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INVESTIGATION INTO THE HYDROLOGIC CHARACTERISTICS OF THE WESTWATER AND SHUMWAY ARROYOS IN THE VICINITY OF THE SAN JUAN GENERATING STATION SAN JUAN COUNTY, NEW MEXICO

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INTRODUCTION

Between March 2005 and February 2006 METRIC Corporation and Public Service Company of New Mexico's San Juan Generating Station personnel conducted an investigation to evaluate the hydrologic characteristics of the Westwater and Shumway Arroyos in the vicinity of the San Juan Generating Station. Flow measurements were made at 13 stations along the arroyos on a monthly basis, and water samples were collected and analyzed at four of the stations on a monthly basis, when water was present. The investigation design, data analysis and report preparation were conducted by METRIC Corporation. The fieldwork (i.e. flow measurements and water sample collection were performed by San Juan Generating Station personnel. The water sample analyses were performed by Green Analytical Laboratory in Durango, Colorado.

SURFACE WATER FLOW MEASUREMENTS

Flow measurements were made at 13 stations (S-1 to S-13 on FIGURE 1) along an approximate four-mile long reach of the Westwater and Shumway Arroyos. The flow measurements were made using a standard USGS mini-current meter and a standard wading rod. The velocity area method was used. Velocity measurements were taken at 0.6 of the total depth below the water surface as described in USGS, 1977. The 13 flow measurement stations shown on FIGURE 1 are described as follows:

- Station S-1 is located in the redirected Westwater Arroyo channel just downstream from the haul road crossing. This section is upstream from most San Juan Generating Station activity and downstream from some San Juan Mine activities, notably Pinon Pit.

- Station S-2 is located in the Westwater Arroyo diversion just upstream from its confluence with the Shumway Diversion.

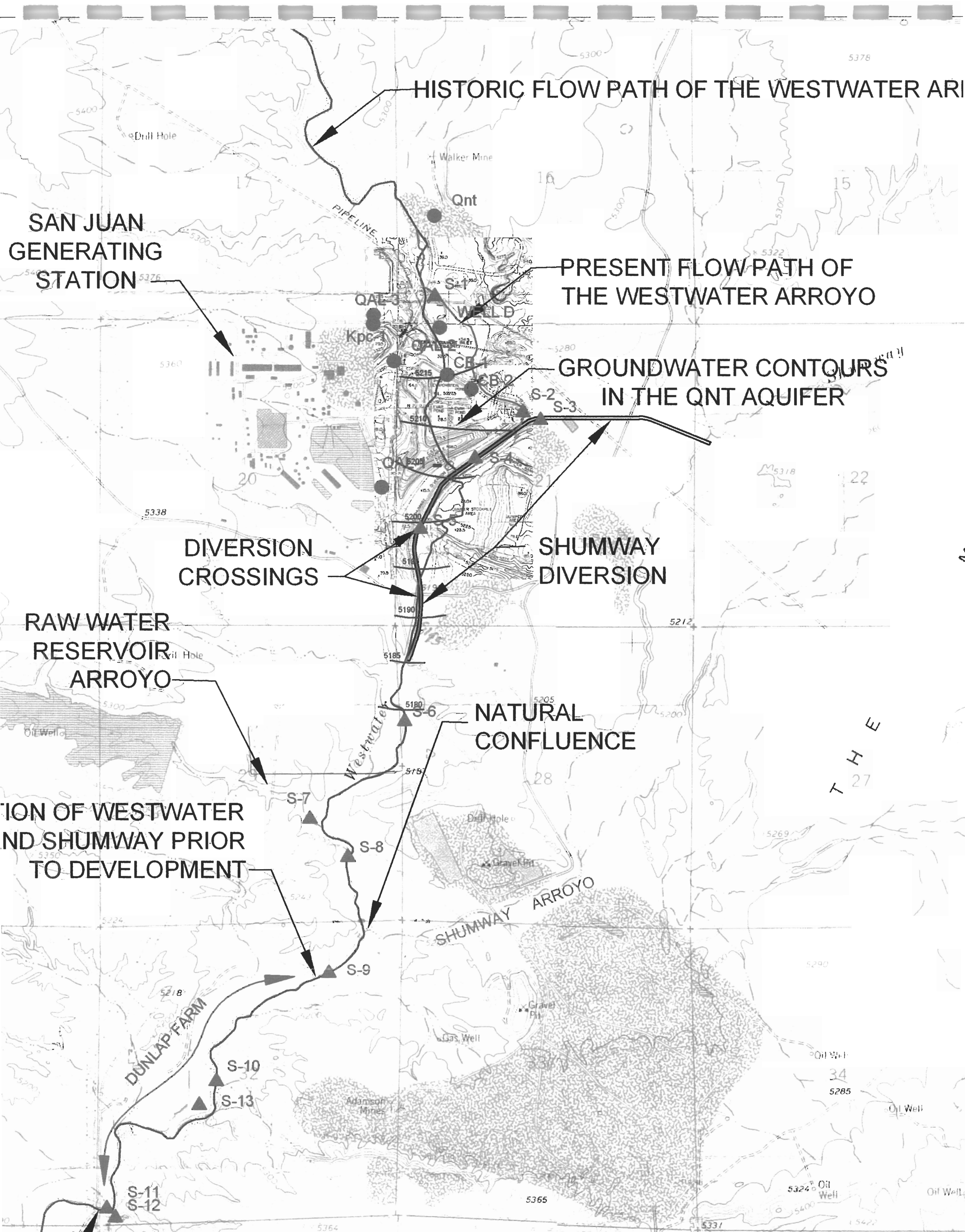
- Station S-3 is located in the Shumway Diversion just upstream from its confluence with the Westwater Diversion.

- Station S-4 is located at the upstream edge of a seep occasionally observed in the Shumway Diversion.

- Station S-5 is located just upstream from the La Plata haul road crossing in the Shumway Diversion.

- Station S-6 is located in the Westwater Arroyo at the San Juan Mine irrigation water pipeline crossing.

- Station S-7 is located in the Raw Water Reservoir Arroyo just upstream fro its confluence with the Westwater Arroyo.



HISTORIC FLOW PATH OF THE WESTWATER AR
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- Station S-8 is located in the Westwater Arroyo just downstream from the red gravel road crossing.

- Station S-9 is located in the Shumway Arroyo at the upstream edge of the Dunlap Farm.

- Station S-10 is located in the Shumway near the middle of the Dunlap Farm.

- Station S-11 is located in the Shumway Arroyo at the downstream edge of the Dunlap Farm and just upstream from Power Plant Road Crossing.

- Station S-12 is located in the Farmers Mutual Ditch Wastewater. This flow is included in the measurements made at S-11.

- Station S-13 is located in the Wasteway from the Dunlap Farm irrigation storage reservoir. This flow is included in the measurements made at S-11.

The results of the 12 monthly flow measurement surveys are summarized in TABLE 1. The field measurements and calculations are presented in APPENDIX A. In TABLE 1 a "DRY" entry indicates no water was present, whereas "0.00" entry indicates there was standing water but it was not perceptibly flowing.

ARROYO WATER QUALITY SAMPLING

Water samples were collected at four of the stations (S-4, S-5, S-8 and S-11) when water was present. The samples were preserved and sent to Green Analytical Laboratory for analysis of major ions, metals, TDS, Conductivity, Nitrate, pH and phenols. The analytical results are summarized in TABLE 2.

CONCLUSIONS RESULTING FROM FLOW MEASUREMENTS

Based on the flow measurements conducted during the preceding 12 months (TABLE 1), the upper reaches of the Westwater Arroyo (S-1 and S-2) and the upper reaches of the Shumway Diversion (S-3) are characterized as ephemeral streams (i.e., they flow only in direct response to precipitation events). The reach of the Shumway Diversion represented by S-4 may be characterized as an ephemeral or perhaps intermittent stream (i.e. it flows seasonably). The lower reach of the Shumway Diversion represented by S-5 and the reach of the Westwater Arroyo represented by S-6 are characterized as intermittent streams. They exhibit seasonal flow.

TABLE 1
PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE FLOW MEASUREMENT SUMMARY

DATE	S1 WESTWATER @ HAUL ROAD		S2 WESTWATER @ DIVERSION		S3 DIVERSION UPSTREAM FROM WESTWATER		S4 DIVERSION SEEP		S5 DIVERSION @ BRIDGE		S6 WESTWATER @ PIPELINE		S7 RAW WATER RESERVOIR ARROYO		S8 RED BRICK ROAD		S9 UPSTREAM @ DUNLAP FARM		S10 MIDDLE @ DUNLAP FARM		S11 MEASURED DOWNSTREAM @ DUNLAP FARM		S11-S13= S11 ACTUAL		S12 DITCH OVERFLOW		S13 IRRIGATION RETURN FLOW		S11-S12
	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)	(gpm)
3/16/05	DRY	DRY	DRY	DRY	DRY	DRY	0.00	0.00	0.04	17.95	0.02	8.98	0.00	0.00	0.08	35.90	0.06	26.93	0.07	31.42	0.13	58.34	0.13	58.34	DRY	DRY	DRY	DRY	58.344
4/19/05	DRY	DRY	DRY	DRY	DRY	DRY	0.00	0.00	0.04	17.95	0.04	17.95	0.02	8.98	0.07	31.42	0.05	22.44	0.07	31.42	0.54	242.35	0.54	242.35	0.28	125.66	DRY	DRY	116.69
5/18/05	DRY	DRY	DRY	DRY	DRY	DRY	0.00	0.00	0.03	13.46	0.05	22.44	0.00	0.00	0.05	22.44	0.02	8.98	0.13	58.34	0.56	251.33	0.56	251.33	0.09	40.39	DRY	DRY	210.94
6/15/05	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	0.03	13.46	0.01	4.49	0.00	0.00	0.00	0.00	0.00	0.00	0.11	49.37	0.71	318.65	0.69	309.67	0.08	35.90	DRY	DRY	282.74
7/14/05	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	0.00	0.00	0.00	0.00	DRY	DRY	DRY	DRY	DRY	DRY	0.06	26.93	0.69	309.67	0.69	309.67	DRY	DRY	DRY	DRY	309.67
8/17/05	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	0.00	0.00	0.00	0.00	DRY	DRY	DRY	DRY	DRY	DRY	0.09	40.39	0.55	246.84	0.16	71.81	DRY	DRY	0.39	175.03	246.84
9/21/05	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	0.03	13.46	0.00	0.00	DRY	DRY	DRY	DRY	DRY	DRY	0.09	40.39	0.40	179.52	0.40	179.52	DRY	DRY	DRY	DRY	179.52
10/18/05	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	0.03	13.46	0.01	4.49	DRY	DRY	0.02	8.98	0.00	0.00	0.07	31.42	0.46	206.45	0.46	206.45	DRY	DRY	DRY	DRY	206.45
11/16/05	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	0.04	17.95	0.02	8.98	DRY	DRY	0.08	35.90	0.01	4.49	0.07	31.42	0.51	228.89	0.51	228.89	DRY	DRY	DRY	DRY	228.89
12/13/05	DRY	DRY	DRY	DRY	DRY	DRY	0.00	0.00	0.03	13.46	0.02	8.98	DRY	DRY	0.08	35.90	0.01	4.49	0.07	31.42	0.43	192.98	0.51	228.89	DRY	DRY	DRY	DRY	192.98
1/19/06	DRY	DRY	DRY	DRY	DRY	DRY	0.00	0.00	0.03	13.46	0.02	8.98	DRY	DRY	0.08	35.90	0.01	4.49	0.07	31.42	0.41	184.01	0.51	228.89	DRY	DRY	DRY	DRY	184.01
2/14/06	DRY	DRY	DRY	DRY	DRY	DRY	0.00	0.00	0.03	13.46	0.02	8.98	DRY	DRY	0.08	35.90	0.01	4.49	0.07	31.42	0.43	192.98	0.51	228.89	DRY	DRY	DRY	DRY	192.98

SITE ID	Lab ID # ID-Record	Sample Date	Nitrogen ppm	TDS ppm	Cond. umhos	Phenols mg/L	pH s.u
S-4	Green	3/9/2005	0.92	19800	28900	0.023	7.9
S-4	Green	4/19/2005	0.04	36200	55000	<0.005	9.0
S-4	Green	5/18/2005	0.38	38500	55800	0.109	8.2
S-4	Green	6/16/2005	Dry no sample				
S-4		7/15/2005	Dry no sample				
S-4		8/17/2005	Dry no sample				
S-4		9/22/2005	no sample	flash flood 9/10/05 flow approx 3 feet dee			
S-4		10/18/2005	no sample				
S-4	Green	11/16/2005	0.21	24700	33700	0.15	8.2
S-4		12/13/2005	frozen no sample				
S-4		1/19/2006	frozen no sample				
S-4		2/14/2006	frozen no sample				

Mn mg/L	Hg mg/L	Mo mg/L	Ni mg/L	Se mg/L	Ag mg/L	U mg/L	Zn mg/L
1.725	<0.0002	0.014	0.113	0.025	0.00038	0.086	0.024
0.405	<0.0002	0.014	0.156	0.09	<0.005	0.054	0.02
1.762	<0.0002	0.033	0.166	0.08	0.0013	0.038	<0.01
<0.00005	<0.0002	0.001	<0.0005	<0.001	0.0001	0.0003	0.002

SITE ID	Lab ID #	Sample	Nitrogen	TDS	Cond.	Phenols	pH
S-5	Green	3/9/2005	11.8	9600	12600	<0.005	8.01
S-5	Green	4/19/2005	13.2	9320	12400	<0.005	8.27
S-5	Green	5/18/2005	5.43	8220	11100	<0.005	7.68
S-5	Green	6/16/2005	0.39	9640	12900	<0.005	7.77
S-5	Green	7/15/2005	0.15	9510	12700	<0.005	7.81
S-5	Green	8/17/2005	1.42	6270	7810	<0.005	7.98
S-5	Green	9/22/2005	4.15	8940	10800	0.028	8
S-5	Green	10/18/2005	5.86	8680	11300	0.056	7.95
S-5	Green	11/16/2005	7.82	9650	12200	0.167	7.95
S-5	Green	12/13/2005	12.4	9460	11600	<0.005	7.45
S-5	Green	1/19/2006	9.11	9710	11800	0.063	7.86
S-5	Green	2/14/2006	9.13	8830	11500	0.072	7.87

Mn	Hg	Mo	Ni	Se	Ag	U	Zn
0.122	<0.0002	0.003	0.084	0.021	0.00006	0.049	0.012
0.074	<0.0002	0.003	0.083	0.03	<0.0005	0.04	<0.01
0.299	<0.0002	0.008	0.078	0.02	0.0005	0.029	<0.01
0.413	<0.0002	0.002	0.069	0.022	<0.00005	0.043	0.008
0.387	<0.0002	0.003	0.074	0.018	<0.00005	0.032	0.009
0.387	<0.0002	0.003	0.046	0.012	0.0006	0.017	0.003
0.038	<0.0002	<0.00005	0.094	0.017	0.0002	0.029	0.003
0.135	<0.0002	0.001	0.053	0.058	<0.00005	0.023	0.009
0.121	<0.0002	0.002	0.076	0.021	0.0001	0.042	0.008
0.28	<0.0002	0.004	0.084	0.028	<0.00005	0.05	0.007
0.172	<0.0002	<0.00005	0.038	0.024	<0.00005	0.045	0.013
0.095	<0.0002	0.007	0.129	0.047	0.00007	0.039	0.011

SITE ID	Lab ID #	Sample	Nitrogen	TDS	Cond.	Phenols	pH
S-8	Green	3/9/2005	6.07	9280	10800	<0.005	7.98
S-8	Green	4/19/2005	5.74	9160	10800	<0.005	7.6
S-8	Green	5/18/2005	1.5	8960	10800	<0.005	7.66
S-8	Green	6/16/2005	0.05	6140	6980	0.007	7.71
S-8		7/15/2005	Dry no sample				
S-8		8/17/2005	no sample				
S-8		9/22/2005	no sample				
S-8	Green	10/18/2005	1.83	7420	9180	0.027	8.33
S-8	Green	11/16/2005	2.61	4970	6430	<0.005	8.11
S-8	Green	12/13/2005	2.04	4510	4960	<0.005	7.38
S-8	Green	1/19/2006	5.24	5270	6370	<0.005	7.86
S-8	Green	2/14/2006	3.01	4760	5940	<0.005	7.77

Mn	Hg	Mo	Ni	Se	Ag	U	Zn
0.251	<0.0002	0.003	0.085	0.026	<0.00005	0.04	0.012
0.323	<0.0002	0.004	0.092	0.03	<0.0005	0.029	<0.01
0.506	0.0003	0.006	0.093	0.02	<0.0005	0.023	<0.01
0.266	<0.0002	0.002	0.042	0.009	<0.00005	0.016	0.007
0.009	<0.0002	0.002	0.059	0.057	<0.00005	0.018	0.009
0.013	<0.0002	0.002	0.048	0.012	0.00006	0.02	0.006
0.274	<0.0002	0.024	0.037	0.011	<0.00005	0.018	0.011
0.09	<0.0002	0.001	0.049	0.014	<0.00005	0.022	0.008
0.112	<0.0002	0.001	0.1	0.026	0.00006	0.017	0.007

4/15/05 irr. Started | 10/15/05 irr. Stopped

SITE ID	Lab ID #	Sample	Nitrogen	TDS	Cond.	Phenols	pH
S-11	Green	3/9/2005	0.06	4710	5770	<0.005	7.68
S-11	Green	4/19/2005	0.37	880	1420	<0.005	7.78
S-11	Green	5/18/2005	0.1	2610	3700	<0.005	7.49
S-11	Green	6/16/2005	0.11	2790	3850	<0.005	7.79
S-11	Green	7/15/2005	0.27	2180	3010	<0.005	7.7
S-11	Green	8/17/2005	0.02	2470	3230	0.006	7.9
S-11	Green	9/22/2005	0.37	2890	3450	0.03	7.78
S-11	Green	10/18/2005	0.4	1640	2140	0.014	7.71
S-11	Green	11/16/2005	0.75	4460	5600	<0.005	7.71
S-11	Green	12/13/2005	1.33	4830	5880	<0.005	7.38
S-11	Green	1/19/2006	1.81	4810	5800	<0.005	7.58
S-11	Green	2/14/2006	1.01	4360	5530	0.047	7.64

Mn	Hg	Mo	Ni	Se	Ag	U	Zn
1.07	<0.0002	0.003	0.028	0.005	<0.00005	0.02	0.013
0.101	0.002	0.002	0.008	<0.01	<0.0005	0.003	0.02
0.504	<0.0002	0.004	0.013	<0.01	<0.0005	0.007	<0.01
0.208	<0.0002	0.002	0.014	0.004	<0.00005	0.01	0.004
0.305	<0.0002	0.002	0.011	0.004	<0.00005	0.01	0.003
0.27	<0.0002	0.194	0.011	0.002	0.00024	0.008	0.04
0.643	<0.0002	<0.00005	<0.0005	0.002	0.00017	0.011	<0.001
0.366	<0.0002	0.001	0.006	0.037	<0.00005	0.005	0.008
0.577	<0.0002	0.002	0.022	0.004	<0.00005	0.022	0.005
0.612	<0.0002	0.016	0.031	0.01	<0.00005	0.025	0.009
0.593	<0.0002	0.002	0.029	0.004	<0.00005	0.022	0.005
0.392	<0.0002	0.001	0.133	0.015	0.00005	0.017	0.005

METRIC Corporation's investigations of the Westwater and Shumway drainages conducted between 1981 and 1984 established the presence of a naturally occurring linear aquifer within the unconsolidated sediments, (Qnt and Qal) of those two drainages. That aquifer passes along the east side of the San Juan Generating Station, (see FIGURE 1).

From 1987 to 1999, METRIC Corporation conducted 12 annual inspections of the entire length of the Shumway and Westwater Diversions for San Juan Coal Company. The purpose of the inspections was to monitor erosion occurring in the diversion. During those inspections, we noted a reach of the diversion from the bridge upstream for a distance of about 700 ft. where flow was generally visible. In that 700 ft. reach of the diversion we also noted scour had lowered the channel bottom 2 ft. to 7 ft. below the original constructed elevations.

It is our opinion that the flow in this reach of the Shumway Diversion is the result of the diversion bottom having been excavated to elevations lower than the naturally occurring water table in the sediments into which the diversion was constructed. The scour, which has occurred in the diversion channel bottom, has further exposed the water table. It is our opinion that the observed flows at S-4, S-5 are the result of the excavation and subsequent erosion in the Shumway Diversion having exposed the alluvial water table in those areas.

It is possible that erosion in the Westwater Arroyo has also exposed the water table at Station S-6. Station S-7 represents conditions in the lower reach of the Raw Water Reservoir Arroyo upstream from the Westwater Arroyo. This reach may be ephemeral or intermittent. During March, April May and June 2005 water was present at this station. Subsequent to June 2005, it was dry. Several beaver ponds were drained in the area near the downstream slope of the Raw Water Reservoir dam in December 2004 and again in January 2006. If the beaver ponds can be kept drained, this reach may remain ephemeral.

The reach of the Westwater Arroyo represented by Station S-8 and the reach of the Shumway Arroyo represented by S-9 appear to be intermittent streams. It is possible that the water table may be above the arroyo bottom seasonally, or there may be some other explanation. The reach of the lower Shumway Arroyo represented by Stations S-10 and S-11 are characterized as a perennial reach (i.e. the stream flows throughout the year). The principal source of the perennial flow is irrigation return flow resulting from application of irrigation water to the Dunlap Farm (FIGURE 1). The existence of a series of beaver dams throughout this reach help to ensure that the reach flows throughout the year. According to LaRay Collyer, May 23, 2003, personal communication, irrigation at the Dunlap Farm began in the late 1960's (probably 1967). Earlier aerial photos of the area indicate this reach of the Shumway Arroyo was ephemeral before that date.

Flows, which occur at Stations S-12 and S-13, are the direct result of irrigation being wasted back to the Arroyo during the irrigation season.

CONCLUSIONS RESULTING FROM ARROYO WATER QUALITY ANALYSES
The Qnt aquifer is a linear saturated unconsolidated deposit, which generally follows the historic flow path of the Westwater Arroyo and then the flow path of the Shumway Arroyo downstream from the natural confluence (FIGURE 1). The aquifer is about 1000 feet wide and 20 feet thick in the vicinity of the San Juan Generating Station.

CB1

Based on the geometry of the saturated unconsolidated deposits (i.e., Qnt and Qal) wells Qnt, Well D, C13-1 and CB-2 and surface water sampling sites S-4 and S-5 are along the groundwater flow path in the Qnt aquifer from upstream to downstream. Wells Qal-3, 2 and 1 are completed in groundwater tributaries to the Qnt aquifer, which enter from the west, the area where the San Juan Generating Station is located. Qal-3 samples a groundwater tributary, which enters the Qnt aquifer between wells Qnt and Well D. Qal-2 samples a groundwater tributary, which enters the Qnt aquifer between wells Well D and CB-1. Qal-1 samples a groundwater tributary, which enters the Qnt aquifer between S-4 and S-5.

Recent water quality data for the monitoring wells and surface water sampling sites discussed above have been plotted on FIGURE 2. The supporting water quality data is in APPENDIX B. A preliminary analysis of FIGURE 2 suggests that the waters at Well D, CB-1, S-5 S-4 and CB-2 are all mixtures of the upstream Qnt aquifer water represented by the Qnt sample and groundwater flow coming from the Generating Station area represented by the Qal-1, 2 and 3 samples, because the Well D, CB-1, S-5, S-4 and CB-2 samples all plot on a straight line between Qnt-1 and Qal-1, 2 and 3. The variations in TDS along the groundwater flow path can be explained by concentration by evapotranspiration and dilution by the tributary flow along the flow path.

In summary, the data presented provides us with reasonable confidence that the water sampled at S-4 and S-5 contains a component of groundwater coming from the Generating Station area.

The sources of the arroyo water sampled at station S-8 are difficult to explain due to a general lack of groundwater data in the area. The arroyo water sampled at station S-11 almost certainly consists of Qnt groundwater with direct contributions of Farmers Mutual Ditch irrigation water and irrigation water, which percolates downward from the irrigated fields of the Dunlap Farm (FIGURE 1) and enters the Qnt aquifer.

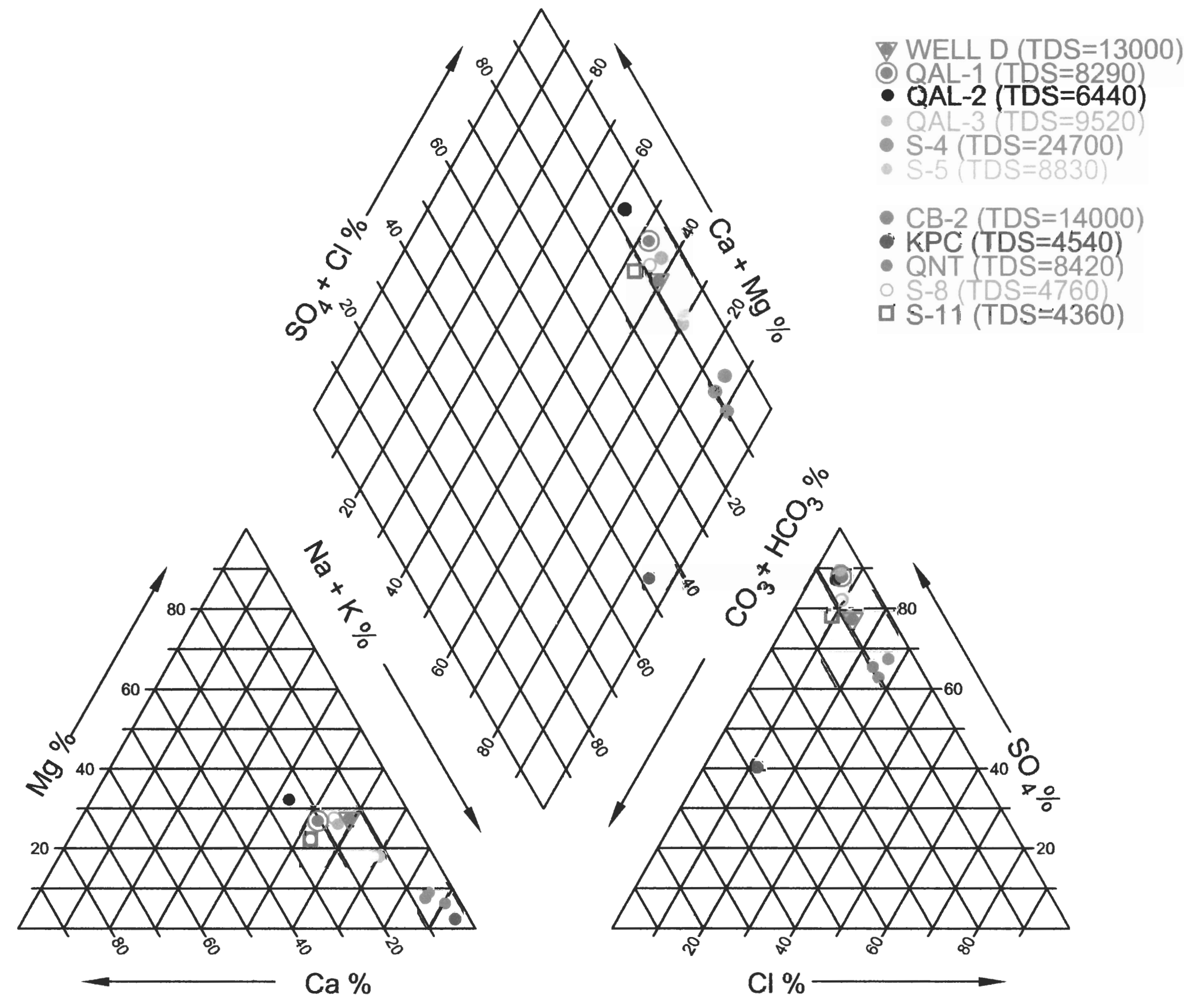

FIGURE 2
TRILINEAR DIAGRAM

RECOMMENDATIONS

In the upper reach of the Qnt aquifer, represented by stations S-4 and S-5, it might be worthwhile to install two additional Qnt monitoring wells, one just west of S-4 and one just west of S-5. These wells could provide additional confidence

from the hydraulic point of view, that groundwater from beneath the Generating Station area is flowing into the Qnt aquifer.

In the middle reach of the Qnt aquifer, represented by stations S-6, S-7 and S-8, substantial additional data is needed to establish the hydraulic characteristics of this reach. Several additional monitoring wells and leachate studies would be required. However, from a regulatory perspective such analysis may not be necessary. It may, on the other hand, be relevant from a third party lawsuit perspective.

In the lower reach of the Qnt aquifer, represented by S-9, S-10, S-11, S-12 and S-13, there does not seem to be any controversial issues from either a regulatory or a third party lawsuit perspective. As a result, additional investigations in this reach do not seem to be warranted.

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APPENDIX A

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 3/16/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0.25		60	0.03	0.000	0.00
2.5	0.25	44	60	0.05	0.735	0.04
5.0	0.1		60	0.01	0.000	0.00
5.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
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			60			
			60			

TOTAL Q 0.04

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 3/16/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0		60	0.00	0.000	0.00
3.0	0.1	0	60	0.03	0.000	0.00
6.0	0.2	12	60	0.05	0.223	0.01 *
9.0	0.2	11	60	0.05	0.207	0.01 *
12.0	0		60	0.00	0.000	0.00
12.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.02

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S7
DATE 3/16/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0.05		60	0.01	0.000	0.00
3.0	0.25	3	60	0.06	0.079	0.00 *
6.0	0.05		60	0.01	0.000	0.00
6.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S8
DATE 3/16/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
3.0	0.5	7	60	0.13	0.143	0.02 *
6.0	0.5	16	60	0.13	0.287	0.04
9.0	0.5	7	60	0.13	0.143	0.02 *
12.0	0.5	2	60	0.13	0.063	0.01 *
15.0	0.45	0	60	0.11	0.000	0.00
18.0	0.45	0	60	0.11	0.000	0.00
21.0	0.45	0	60	0.11	0.000	0.00
24.0	0.35	0	60	0.09	0.000	0.00
27.0	0	0	60	0.00	0.000	0.00
27.0			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.08

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S9
DATE 3/16/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0.3	0	60	0.04	0.000	0.00
3.0	0.3	45	60	0.08	0.752	0.06
6.0	0.3	0	60	0.04	0.000	0.00
6.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.06

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 3/16/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
3.0	0.25	0	60	0.06	0.000	0.00
6.0	0.3	25	60	0.08	0.431	0.03
9.0	0.4	20	60	0.10	0.351	0.04
12.0	0.3	4	60	0.08	0.095	0.01 *
15.0	0.1	0	60	0.03	0.000	0.00
18.0	0.05	0	60	0.01	0.000	0.00
21.0	0		60	0.00	0.000	0.00
21.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.07

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 3/16/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
3.0	0.25	0	60	0.06	0.000	0.00
6.0	0.25	2	60	0.06	0.063	0.00 *
9.0	0.3	2	60	0.08	0.063	0.00 *
12.0	0.4	8	60	0.10	0.159	0.02 *
15.0	0.45	9	60	0.11	0.175	0.02 *
18.0	0.4	10	60	0.10	0.191	0.02 *
21.0	0.35	9	60	0.09	0.175	0.02 *
24.0	0.35	8	60	0.09	0.159	0.01 *
27.0	0.25	7	60	0.06	0.143	0.01 *
30.0	0.4	7	60	0.10	0.143	0.01 *
33.0	0.3	2	60	0.08	0.063	0.00 *
36.0	0.3	2	60	0.08	0.063	0.00 *
39	0.35	0	60	0.09	0.000	0.00
42	0.35	0	60	0.09	0.000	0.00
45	0.35	0	60	0.09	0.000	0.00
48	0.35	0	60	0.09	0.000	0.00
51	0	0	60	0.00	0.000	0.00
51			60			

TOTAL Q 0.13

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 4/18/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0.25		60	0.03	0.000	0.00
2.5	0.25	42	60	0.05	0.703	0.04
5.0	0.1		60	0.01	0.000	0.00
5.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.04

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 4/19/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0		60	0.00	0.000	0.00
3.0	0.05	0	60	0.01	0.000	0.00
6.0	0.2	22	60	0.05	0.383	0.02
9.0	0.2	21	60	0.05	0.367	0.02
12.0	0		60	0.00	0.000	0.00
12.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.04

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S8
DATE 4/19/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
3.0	0.5	5	60	0.13	0.111	0.01 *
6.0	0.5	14	60	0.13	0.255	0.03
9.0	0.5	7	60	0.13	0.143	0.02 *
12.0	0.5	1	60	0.13	0.047	0.01 *
15.0	0.45	0	60	0.11	0.000	0.00
18.0	0.45	0	60	0.11	0.000	0.00
21.0	0.45	0	60	0.11	0.000	0.00
24.0	0.3	0	60	0.08	0.000	0.00
27.0	0	0	60	0.00	0.000	0.00
27.0			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.07

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S9
DATE 4/19/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0.3	0	60	0.04	0.000	0.00
3.0	0.3	38	60	0.08	0.639	0.05
6.0	0.25	0	60	0.03	0.000	0.00
6.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.05

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 4/19/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
3.0	0.25	0	60	0.06	0.000	0.00
6.0	0.3	24	60	0.08	0.415	0.03
9.0	0.4	20	60	0.10	0.351	0.04
12.0	0.3	3.5	60	0.08	0.087	0.01 *
15.0	0.05	0	60	0.01	0.000	0.00
18.0	0.05	0	60	0.01	0.000	0.00
21.0	0	0	60	0.00	0.000	0.00
21.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.07

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 4/19/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
3.0	0.05	0	60	0.01	0.000	0.00
6.0	0.05	0	60	0.01	0.000	0.00
9.0	0.6	4.5	60	0.15	0.103	0.02 *
12.0	0.6	12	60	0.15	0.223	0.03 *
15.0	0.6	15	60	0.15	0.271	0.04
18.0	0.6	21	60	0.15	0.367	0.06
21.0	0.6	18	60	0.15	0.319	0.05
24.0	0.6	12	60	0.15	0.223	0.03 *
27.0	0.6	15	60	0.15	0.271	0.04
30.0	0.75	25	60	0.19	0.431	0.08
33.0	0.7	20	60	0.18	0.351	0.06
36.0	0.65	20	60	0.16	0.351	0.06
39	0.7	23	60	0.18	0.399	0.07
42	0.75	26	60	0.19	0.447	0.08
45	0.75	21	60	0.19	0.367	0.07
48	0.75	21	60	0.19	0.367	0.07
51	0.4	23	60	0.10	0.399	0.04
54	0.35	27	60	0.10	0.463	0.05
58	0.1	0	60	0.02	0.000	0.00
58						
			60			

TOTAL Q 0.54

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S12 IRRIGATION DITCH OVERFLOW
DATE 4/19/2005
TECHNICIAN

TAPE (in)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
3.0	0.15	0	60	0.04	0.000	0.00
6.0	0.25	6	60	0.06	0.127	0.01 *
9.0	0.4	10	60	0.10	0.191	0.02 *
12.0	0.5	12	60	0.13	0.223	0.03 *
15.0	0.75	13	60	0.19	0.239	0.04 *
18.0	0.75	14	60	0.19	0.255	0.05
21.0	0.8	15	60	0.20	0.271	0.05
24.0	0.75	15	60	0.19	0.271	0.05
27.0	0.75	6	60	0.19	0.127	0.02 *
30.0	0.75	0	60	0.16	0.000	0.00
32.0	0	0	60	0.00	0.000	0.00
32.0						

TOTAL Q 0.28

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 5/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.2	0	60	0.03	0.000	0.00
0.25	0.2	38	60	0.04	0.639	0.03
0.42	0.1	0	60	0.01	0.000	0.00
0.42			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.03

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 5/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.20	28	60	0.05	0.479	0.02
0.50	0.20	29	60	0.05	0.495	0.02
0.75	0.00	0	60	0.00	0.000	0.00
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.05

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S7
DATE 5/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.20	0	60	0.05	0.000	0.00
0.50	0.25	0	60	0.05	0.000	0.00
0.66	0.00	0	60	0.00	0.000	0.00
0.66			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S8
DATE 5/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.20	0	60	0.03	0.000	0.00
0.25	0.40	5	60	0.10	0.111	0.01 *
0.50	0.40	11	60	0.10	0.207	0.02 *
0.75	0.40	9	60	0.10	0.175	0.02 *
1.00	0.35	0	60	0.09	0.000	0.00
1.25	0.35	0	60	0.09	0.000	0.00
1.50	0.30	0	60	0.08	0.000	0.00
1.75	0.30	0	60	0.08	0.000	0.00
2.00	0.00	0	60	0.00	0.000	0.00
2.00			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.05

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S9
DATE 5/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.15	38	60	0.03	0.639	0.02
0.42	0.10	0	60	0.01	0.000	0.00
0.42			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.02

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 5/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.17	40	60	0.04	0.671	0.03
0.50	0.25	38	60	0.06	0.639	0.04
0.75	0.28	28	60	0.07	0.479	0.03
1.00	0.28	20	60	0.07	0.351	0.02
1.25	0.05	0	60	0.01	0.000	0.00
1.50	0.05	0	60	0.01	0.000	0.00
1.75	0.01	0	60	0.00	0.000	0.00
2.00	0.01	0	60	0.00	0.000	0.00
2.25	0.01	0	60	0.00	0.000	0.00
2.25			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.13

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 5/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.5	0.05	0	60	0.03	0.000	0.00
1.0	0.05	5	60	0.03	0.111	0.00 *
1.5	0.6	10	60	0.30	0.191	0.06 *
2.0	0.6	12	60	0.30	0.223	0.07 *
2.5	0.6	14	60	0.30	0.255	0.08
3.0	0.6	16	60	0.30	0.287	0.09
3.5	0.6	17	60	0.30	0.303	0.09
4.0	0.6	19	60	0.30	0.335	0.10
4.5	0.6	18	60	0.25	0.319	0.08
4.8	0.75	0	60	0.11	0.000	0.00
4.8			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.56

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S12 IRRIGATION DITCH OVERFLOW
DATE 5/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	48	60	0.06	0.800	0.05
0.50	0.12	53	60	0.05	0.880	0.04
1.00	0.00	0	60	0.00	0.000	0.00
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.09

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 6/15/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0	0	60	0.00	0.000	0.00
0.25	0.17	37	60	0.04	0.623	0.02
0.42	0.17	37	60	0.01	0.623	0.01
0.42			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.03

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 6/15/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.08	20 **	60	0.02	0.351	0.01
0.50	0.08	20 **	60	0.02	0.351	0.01
0.66	0.00	0	60	0.00	0.000	0.00
0.66			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.01

* Flow velocity below limits of meter.
** Flow depth not deep enough for meter. Surface velocity measured at 23 clicks/60 se
Surface velocity adjusted by 0.85 to represent average flow velocity

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S7
DATE 6/15/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.20	1	60	0.05	0.047	0.00 *
0.50	0.18	1	60	0.04	0.047	0.00 *
0.66	0.00	0	60	0.00	0.000	0.00
0.66			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S8
DATE 6/15/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.20	0	60	0.05	0.000	0.00
0.50	0.32	0	60	0.08	0.000	0.00
0.75	0.32	0	60	0.08	0.000	0.00
1.00	0.10	0	60	0.03	0.000	0.00
1.25	0.06	0	60	0.02	0.000	0.00
1.50	0.00	0	60	0.00	0.000	0.00
1.50			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S9
DATE 6/15/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.08	0	60	0.01	0.000	0.00
0.33	0.00	0	60	0.00	0.000	0.00
0.33			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 6/15/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.05	0	60	0.01	0.000	0.00
0.50	0.30	43	60	0.08	0.719	0.05
0.75	0.30	43	60	0.08	0.719	0.05
1.00	0.08	8	60	0.02	0.159	0.00 *
1.25	0.05	0	60	0.01	0.000	0.00
1.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.11

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 6/15/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.5	0.08	0	60	0.04	0.000	0.00
1.0	0.1	0	60	0.05	0.000	0.00
1.5	0.3	11	60	0.15	0.207	0.03 *
2.0	0.4	15	60	0.20	0.271	0.05
2.5	0.52	18	60	0.26	0.319	0.08
3.0	0.55	17	60	0.28	0.303	0.08
3.5	0.55	35	60	0.28	0.591	0.16
4.0	0.8	29	60	0.40	0.495	0.20
4.5	0.5	24	60	0.19	0.415	0.08
4.75	0.5	14	60	0.06	0.255	0.02
4.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.71

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S12 IRRIGATION DITCH OVERFLOW
DATE 6/15/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.30	42	60	0.08	0.703	0.05
0.50	0.21	29	60	0.05	0.495	0.03
0.75	0.08	0	60	0.02	0.000	0.00
1.00	0.00	0	60	0.00	0.000	0.00
1.00			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.08

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 7/14/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0	0	60	0.00	0.000	0.00
0.25	0.12	0	60	0.03	0.000	0.00
0.42	0.12	0	60	0.01	0.000	0.00
0.42			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 7/14/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.08	0	60	0.02	0.000	0.00
0.42	0.00	0	60	0.00	0.000	0.00
0.42			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.
Flow depth not deep enough for meter. Surface velocity measured at 23 clicks/60 sec
Surface velocity adjusted by 0.85 to represent average flow velocity

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 7/14/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.05	0	60	0.01	0.000	0.00
0.50	0.33	15	60	0.08	0.271	0.02
0.75	0.33	20	60	0.08	0.351	0.03
1.00	0.12	8	60	0.03	0.159	0.00 *
1.25	0.05	0	60	0.01	0.000	0.00
1.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.06

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 7/14/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.5	0.08	0	60	0.04	0.000	0.00
1.0	0.1	0	60	0.05	0.000	0.00
1.5	0.5	20	60	0.25	0.351	0.09
2.0	0.3	12	60	0.15	0.223	0.03 *
2.5	0.7	22	60	0.35	0.383	0.13
3.0	0.55	25	60	0.28	0.431	0.12
3.5	0.55	26	60	0.28	0.447	0.12
4.0	0.8	22	60	0.40	0.383	0.15
4.5	0.5	18	60	0.13	0.319	0.04
4.5			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.69

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 8/17/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0	0	60	0.00	0.000	0.00
0.25	0.12	0	60	0.03	0.000	0.00
0.42	0.08	0	60	0.01	0.000	0.00
0.42			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 8/17/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.08	0	60	0.02	0.000	0.00
0.42	0.00	0	60	0.00	0.000	0.00
0.42			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.
Flow depth not deep enough for meter. Surface velocity measured at 23 clicks/60 sec
Surface velocity adjusted by 0.85 to represent average flow velocity

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 8/17/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.12	22	60	0.02	0.383	0.01
0.25	0.25	60	60	0.06	0.992	0.06
0.46	0.25	77	60	0.03	1.264	0.03
0.46			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.09

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 8/17/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.5	0.3	0	60	0.15	0.000	0.00
1.0	0.3	10	60	0.15	0.191	0.03 *
1.5	0.3	13	60	0.15	0.239	0.04 *
2.0	0.5	15	60	0.25	0.271	0.07
2.5	0.6	15	60	0.30	0.271	0.08
3.0	0.7	19	60	0.35	0.335	0.12
3.5	0.8	28	60	0.40	0.479	0.19
4.0	0.3	21	60	0.08	0.367	0.03
4.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.55

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S13
DATE 8/17/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.3	0.25	24	60	0.06	0.415	0.03
0.5	0.42	80	60	0.11	1.312	0.14
0.8	0.42	80	60	0.11	1.312	0.14
1.0	0.33	63	60	0.08	1.040	0.09
1.3	0	0	60	0.00	0.000	0.00
1.3			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.39

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 9/21/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.2	0	60	0.03	0.000	0.00
0.25	0.4	4	60	0.10	0.095	0.01 *
0.50	0.5	3	60	0.13	0.079	0.01 *
0.8	0.5	2	60	0.13	0.063	0.01 *
1.0	0.2	0	60	0.03	0.000	0.00
1.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.03

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 9/21/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.08	3	60	0.02	0.079	0.00 *
0.50	0.08	3	60	0.02	0.079	0.00 *
0.75	0.00	0	60	0.00	0.000	0.00
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.
Flow depth not deep enough for meter. Surface velocity measured at 23 clicks/60 sec
Surface velocity adjusted by 0.85 to represent average flow velocity

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 9/21/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.20	20	60	0.03	0.351	0.01
0.25	0.25	24	60	0.06	0.415	0.03
0.50	0.33	35	60	0.08	0.591	0.05
0.75	0.33	28	60	0.04	0.479	0.02
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.09

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 9/21/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.5	0.6	18	60	0.30	0.319	0.10
1.0	0.8	21	60	0.40	0.367	0.15
1.5	0.8	12	60	0.40	0.223	0.09 *
2.0	0.4	5	60	0.20	0.111	0.02 *
2.5	0.7	13	60	0.21	0.239	0.05 *
2.6	0	0	60	0.00	0.000	0.00
2.6			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.40

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 10/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.2	0	60	0.03	0.000	0.00
0.25	0.4	0	60	0.10	0.000	0.00
0.50	0.6	2	60	0.15	0.063	0.01 *
0.75	0.6	2	60	0.15	0.063	0.01 *
1.00	0.6	3	60	0.15	0.079	0.01 *
1.25	0.2	0	60	0.03	0.000	0.00
1.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.03

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 10/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.12	6	60	0.03	0.127	0.00 *
0.50	0.12	8	60	0.03	0.159	0.00 *
0.75	0.00	0	60	0.00	0.000	0.00
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.01

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S8
DATE 10/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.00	0	60	0.00	0.000	0.00
0.50	0.30	4	60	0.08	0.095	0.01 *
0.75	0.30	4	60	0.08	0.095	0.01 *
1.00	0.30	3	60	0.08	0.079	0.01 *
1.25	0.00	0	60	0.00	0.000	0.00
1.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.02

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S9
DATE 10/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.04	0	60	0.01	0.000	0.00
0.50	0.00	0	60	0.00	0.000	0.00
0.50			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.00

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 10/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	16	60	0.06	0.287	0.02
0.50	0.33	22	60	0.08	0.383	0.03
0.75	0.30	25	60	0.04	0.431	0.02
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.07

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 10/18/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.5	0.75	23	60	0.38	0.399	0.15
1.0	0.6	24	60	0.30	0.415	0.12
1.5	0.4	21	60	0.20	0.367	0.07
2.0	0.5	12	60	0.25	0.223	0.06 *
2.5	0.3	20	60	0.15	0.351	0.05
3.0	0	0	60	0.00	0.000	0.00
3.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.46

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 11/16/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.2	0	60	0.03	0.000	0.00
0.25	0.4	0	60	0.10	0.000	0.00
0.50	0.6	4	60	0.15	0.095	0.01 *
0.75	0.6	4	60	0.15	0.095	0.01 *
1.00	0.6	4	60	0.15	0.095	0.01 *
1.25	0.2	0	60	0.03	0.000	0.00
1.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.04

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 11/16/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	9	60	0.06	0.175	0.01 *
0.50	0.25	8	60	0.06	0.159	0.01 *
0.75	0.00	0	60	0.00	0.000	0.00
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.02

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S8
DATE 11/16/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.50	0.50	3	60	0.25	0.079	0.02 *
1.00	0.50	3	60	0.25	0.079	0.02 *
1.50	0.50	4	60	0.25	0.095	0.02 *
2.00	0.50	3	60	0.19	0.079	0.01 *
2.25	0.00	0	60	0.00	0.000	0.00
2.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.08

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S9
DATE 11/16/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	4	60	0.06	0.095	0.01 *
0.50	0.25	5	60	0.06	0.111	0.01 *
0.75	0.00	0	60			
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.01

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 11/16/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	18	60	0.06	0.319	0.02
0.50	0.33	22	60	0.08	0.383	0.03
0.75	0.33	24	60	0.04	0.415	0.02
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.07

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 11/16/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.5	0.75	25	60	0.38	0.431	0.16
1.0	0.6	25	60	0.30	0.431	0.13
1.5	0.5	21	60	0.25	0.367	0.09
2.0	0.5	16	60	0.25	0.287	0.07
2.5	0.3	22	60	0.15	0.383	0.06
3.0	0	0	60	0.00	0.000	0.00
3.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.51

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 12/13/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.2	0	60	0.03	0.000	0.00
0.25	0.3	0	60	0.08	0.000	0.00
0.50	0.5	5	60	0.13	0.111	0.01 *
0.75	0.6	4	60	0.15	0.095	0.01 *
1.00	0.5	4	60	0.13	0.095	0.01 *
1.25	0	0	60	0.00	0.000	0.00
1.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.04

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 12/13/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	7	60	0.06	0.143	0.01 *
0.50	0.25	7	60	0.06	0.143	0.01 *
0.75	0.00	0	60	0.00	0.000	0.00
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.02

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S8
DATE 12/13/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.50	0.50	3	60	0.25	0.079	0.02 *
1.00	0.50	4	60	0.25	0.095	0.02 *
1.50	0.50	4	60	0.25	0.095	0.02 *
2.00	0.50	3	60	0.19	0.079	0.01 *
2.25	0.00	0	60	0.00	0.000	0.00
2.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.08

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S9
DATE 12/13/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	4	60	0.06	0.095	0.01 *
0.50	0.25	4	60	0.06	0.095	0.01 *
0.75	0.00	0	60			
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.01

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 12/13/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	15	60	0.06	0.271	0.02
0.50	0.33	24	60	0.08	0.415	0.03
0.75	0.33	20	60	0.04	0.351	0.01
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.07

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 12/13/2005
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.5	0.6	25	60	0.30	0.431	0.13
1.0	0.5	24	60	0.25	0.415	0.10
1.5	0.5	20	60	0.25	0.351	0.09
2.0	0.4	16	60	0.20	0.287	0.06
2.5	0.3	20	60	0.15	0.351	0.05
3.0	0	0	60	0.00	0.000	0.00
3.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.43

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 1/19/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.2	0	60	0.03	0.000	0.00
0.25	0.3	0	60	0.08	0.000	0.00
0.50	0.5	3	60	0.13	0.079	0.01 *
0.75	0.6	3	60	0.15	0.079	0.01 *
1.00	0.5	3	60	0.13	0.079	0.01 *
1.25	0	0	60	0.00	0.000	0.00
1.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.03

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 1/19/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	6	60	0.06	0.127	0.01 *
0.50	0.25	7	60	0.06	0.143	0.01 *
0.75	0.00	0	60	0.00	0.000	0.00
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.02

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S8
DATE 1/19/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.50	0.40	5	60	0.20	0.111	0.02 *
1.00	0.40	6	60	0.20	0.127	0.03 *
1.50	0.50	6	60	0.25	0.127	0.03 *
2.00	0.00	0	60	0.00	0.000	0.00
2.25	0.00	0	60	0.00	0.000	0.00
2.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.08

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S9
DATE 1/19/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.30	4	60	0.08	0.095	0.01 *
0.50	0.25	4	60	0.06	0.095	0.01 *
0.75	0.00	0	60			
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.01

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 1/19/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	15	60	0.06	0.271	0.02
0.50	0.35	22	60	0.09	0.383	0.03
0.75	0.33	21	60	0.04	0.367	0.02
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.07

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 1/19/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.5	0.5	24	60	0.25	0.415	0.10
1.0	0.5	24	60	0.25	0.415	0.10
1.5	0.5	20	60	0.25	0.351	0.09
2.0	0.4	18	60	0.20	0.319	0.06
2.5	0.3	18	60	0.15	0.319	0.05
3.0	0	0	60	0.00	0.000	0.00
3.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.41

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S5
DATE 2/14/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.2	0	60	0.03	0.000	0.00
0.25	0.3	0	60	0.08	0.000	0.00
0.50	0.5	3	60	0.13	0.079	0.01 *
0.75	0.5	4	60	0.13	0.095	0.01 *
1.00	0.5	3	60	0.13	0.079	0.01 *
1.25	0	0	60	0.00	0.000	0.00
1.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.03

* Flow velocity below limits of meter.

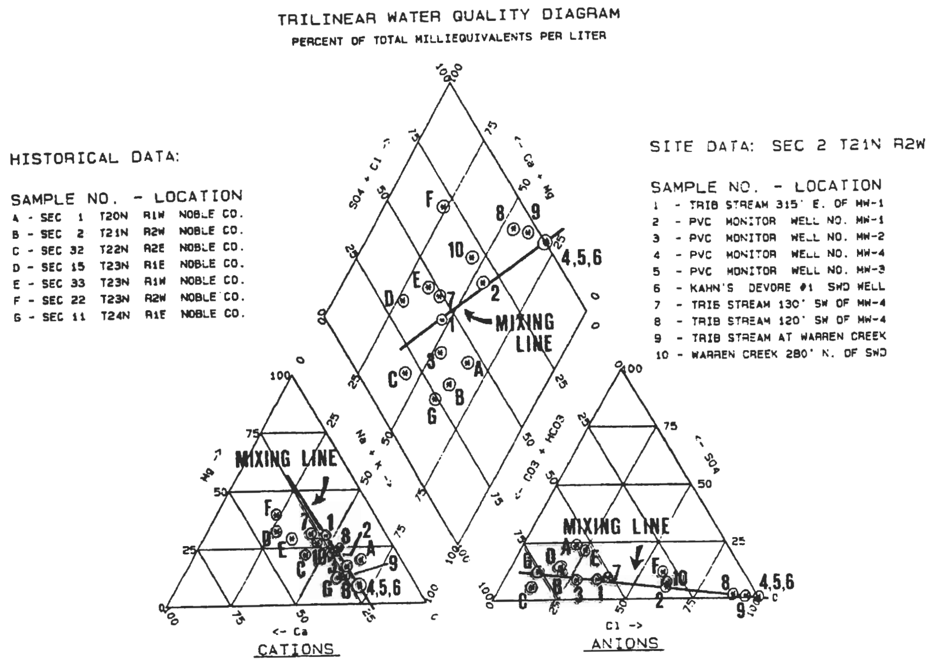

FIGURE 2. Piper plot of historical background (letters) and site (numbers) water quality analyses.

affected by the DeVore SWD well, but high surface runoff may be masking its true influence because of dilution. It should be noted that all samples were obtained within one week after an intense 24-hr, four-inch rainfall event when streams were running nearly full with uncontaminated surface runoff. Hence, a surface dilution effect had undoubtedly masked the full extent of contaminated surface waters. A simple two-end-member mixing line can be drawn in all three plotting positions of the trilinear diagram, as seen in Figure 2. It is interesting to note that in the diamond area, surface project samples appear above this mixing line, while ground water samples appear on or below it. This observation suggests that one or two separate three-end-member mixing models might actually be affecting the diagram. Additional water quality information would be required to substantiate this interpretation.

The sample recovered from well MW-1 (sample 2) shows chemical characteristics midway between uncontaminated surface (sample 1) and contaminated subsurface (samples 4, 5, and 6) waters. It has apparently been influenced by an unknown chloride source. Inspection of the piezometric contour map would suggest that this contamination has a source separate from the DeVore SWD well. However, a radius of endangering influence calculation suggests otherwise. Well MW-1 is completed within 10 feet of the abandoned Devore-Wolfe exploration well (see Figure 1), and is about 670 feet south of the DeVore SWD well. Plugging records indicate that the DeVore-Wolfe well was drilled deeper than the SWD well's injection interval at 3200 feet below ground surface. Surface casing in the DeVore-Wolfe well was set at 120 feet and cemented; most of the remaining steel casing was removed in 1950, and the open borehole was filled with bentonite mud. If a standard (10 pounds per gallon) mud weight were used and it had a 15 percent weight reduction due to settlement or degradation after 35 years, then the DeVore-Wolfe wellbore would have a pressure of about 1413 psig at 3200 feet.

Figure 4 summarizes one possible radius

of influence calculation for the DeVore SWD well; several individual parameters are estimated in the calculation since observations are unavailable. These critical injection zone parameters include: (a) an assumed permeability of 40 millidarcys (equivalent to a transmissivity of about 5.9 feet squared per day); (b) an assumed initial undisturbed piezometric head located 300 feet below ground surface; and (c) an assumed freshwater aquifer base located 200 feet below ground surface. None of this information is required by the Oklahoma Corporation Commission in support of UIC permit applications. The injection rate, time, interval thickness, and injection zone depth were all obtained from required information in the original permit application; injection fluid properties are typical of Oklahoma deep basin brines. The aquifer storage coefficient (S) was estimated from the relationship $S = \gamma b(\alpha + n\beta)$, where γ is the injection fluid specific weight of 64.3 pounds per cubic foot, b is the injection zone thickness of 75 feet, α is the injection zone rock compressibility, n is the porosity, and β is the compressibility of water. Domenico (5, p. 216-235) lists typical values for α according to rock type. For this calculation α was assumed to be 1.6E-8 feet squared per pound, a typical value for mildly fissured to solid rock. The computed value of S = 1.022E-4 is characteristic of a confined aquifer.

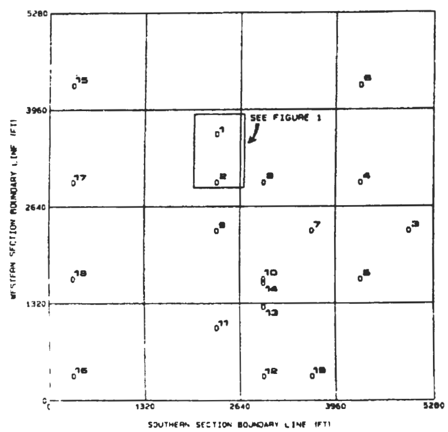

FIGURE 3. Locations of oil and gas exploration wells adjacent to the disposal site. Identification of wells with (year-of-completion; total depth in ft) follows:
1 = Devore SWD (1948; 5141);
2 = Plugged Devore-Wolfe (1949; 5118);
3 = Wiegel #1 (1947; 5139);
4 = Albright #1 (1947; 5137);
5 = Plugged Wiegel #2 (1947; 5138);
6 = Albright #2 (1948; 5157);
7 = Wiegel #3 (1948; 5113);
8 = Albright #3 (1948; 5100);
9 = Wiegel #4 (1948; 5117);
10 = Plugged Dayton #1 (1948; 5106);
11 = Plugged Dayton #2 (1948; 5136);
12 = Wiegel #5 (1949; 5020);
13 = Wiegel #6 (1949; 4994);
14 = Wiegel Twin #6 (1949; 4994);
15 = Plugged Wiegel #7 (1954; 2325);
16 = Christian #1 (1981; 5270);
17 = Floris Dayton #1 (1981; 5233);
18 = Verl Hentges #1 (1981; 5180);
19 = Cinnamon #3 (1981; 5195).

Calculations using Eqs. 1 and 3 yield an R of about 7200 feet, as seen in Figure 4. They also indicate that a resultant downhole pressure in excess of 1400 psig will be produced at the DeVore-Wolfe well after 30 years due to salt water injection at the disposal well. This pressure would be sufficient to allow DeVore SWD brines to migrate up the DeVore-Wolfe wellbore and enter the freshwater aquifer near MW-1. Furthermore, by using the developments of Hoopes and Harleman (10), it can be shown that sufficient time has elapsed to allow undiluted SWD brines to travel in the injection interval to the DeVore-Wolfe wellbore. This interpretation is further supported by the trilinear diagram characterization of shallow ground waters, and would not have been possible if only chloride concentrations had been available.

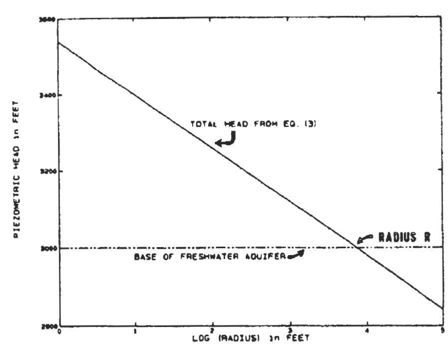

FIGURE 4. Graphical representation of the radius of endangering influence calculation for the DeVore SWD well.

CONCLUSIONS

This paper has presented several management tools that can be used to assess potential environmental impacts resulting from salt-water injection wells. A simple case history has demonstrated their relative importance in practical problems. While this technology has existed for many years, certain fundamental implications have apparently gone unnoticed in the implementation of the UIC program as it applies to Class II injection wells. Hence, the objective of presenting this case history is to refocus attention on the supporting information required in individual state UIC permit applications. Most hydrologists will immediately recognize the importance of requiring SWD well operators to physically measure hydrostatic pressure levels in potential injection intervals. This information should be required on all permit applications where the radius of endangering influence calculation is made. Furthermore, a sensitivity analysis of transmissivity (T) in the Cooper-Jacob equation will quickly demonstrate its importance in computing an upconing value for s. In those situations where the injection zone's initial hydrostatic pressure is near the base of the lowest freshwater aquifer, then physical measurements for T (or its petroleum effective equivalent of permeability) should also be required if the injection well is adjacent to other abandoned or production wells, or is located in geologic settings where extensive vertical fracture permeability is expected. If these parameters are fixed via physical observations, then variations in the expected range of the aquifer storage coefficient (S) will be of secondary importance. For existing injection wells where this information has not been documented, then a shallow ground water monitoring network could be installed. While a more detailed assessment would still be advocated by many, it is imperative to initiate these fundamental requirements if a meaningful UIC program for Class II wells is to be maintained.

Finally, the trilinear diagram technique of water quality analysis can be extremely useful in differentiating uncontaminated and brine-contaminated shallow ground and surface waters. These analyses require that all major ion parameters be measured, instead of simply using chloride as a brine tracer.

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TECHNICAL GUIDANCE MANUAL FOR HYDROGEOLOGIC INVESTIGATIONS AND GROUND WATER MONITORING

CHAPTER 12
GROUND WATER QUALITY DATA ORGANIZATION AND INTERPRETATION

February 1995

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CHAPTER 12

GROUND WATER QUALITY DATA ORGANIZATION AND INTERPRETATION

Large amounts of ground water quality data can be generated during a hydrogeologic investigation and/or ground water monitoring program. Proper interpretation of the data is necessary to enable sound decisions. It is important that the data be: 1) organized and presented in a manner that is easily understood and 2) checked for technical soundness, statistical validity, proper documentation, and regulatory or programmatic compliance.

Project goals and data evaluation procedures often are dictated by regulatory requirements. For example, an owner or operator of an interim status land-based hazardous waste management unit or a solid waste landfill must use statistics in his/her monitoring program to determine whether contaminants have been released to ground water. The methodology used to evaluate risk to human health and/or the environment also may depend on the regulatory program. Additionally, methods utilized to interpret data may be ordered on a site-specific basis.

VALIDATION

Validation is crucial for the correct assessment of ground water quality data. Data must be systematically compared against a set of criteria to provide assurance that the data are adequate for the intended use. Validation consists of editing, screening, checking, auditing, verification, certification, and review (Canter et al., 1988).

The methods used to define site hydrogeology and collect ground water samples need to be scrutinized. In addition, data should be evaluated using field and trip blank(s) (see Chapter 10) to help verify that sampling techniques were appropriate. Laboratory data validation is completed by a party other than the laboratory performing the analysis. U.S. EPA guidance for validation of chemical analyses (U.S. EPA, 1988a, b) stressed the importance of evaluating analytical methods and procedures such as sample holding times, instrument calibration, method blanks, surrogate recoveries, matrix spikes, and field duplicates.

ORGANIZATION AND INTERPRETATION TOOLS

Ground water quality data should be compiled and presented in a manner convenient for interpretation. Presentation methods include tabular, map, and graphic. Interpretation techniques include statistics and modeling. The appropriate tools depend on the goals of the monitoring program.

TABULAR

Tables of data are the most common form in which the chemical analyses are reported. Tables generally are sorted by well, type of constituent, and/or time of sampling. For most constituents, data are expressed in milligrams per liter (mg/l) or micrograms per liter (µg/l). Data should be organized and presented in tabular form or as dictated by regulatory or program requirements. Reports from the laboratory also should be submitted. Some Ohio EPA programs are beginning to require ground water quality data to be submitted in a computer-based format. However, before submitting data in an electronic format, regulated entities should check with the appropriate program to determine the preferred media. Chapter 2 summarizes the Agency's organization and authority to require monitoring.

MAP

Isopleth maps are contour maps constructed by drawing lines representing equal concentrations of dissolved constituents or single ions (Figure 12.1). These maps, when combined with site-specific geologic/hydrogeologic characteristics (see Chapter 3), are useful in tracking plumes. However, their applicability depends on the homogeneity of ground water quality with depth and the concentration gradient between measuring points. Restricted sampling points in either the vertical or horizontal direction limit usefulness (Sara and Gibbons, 1991). Questionable data or areas lacking sufficient data should be represented by dashed lines.

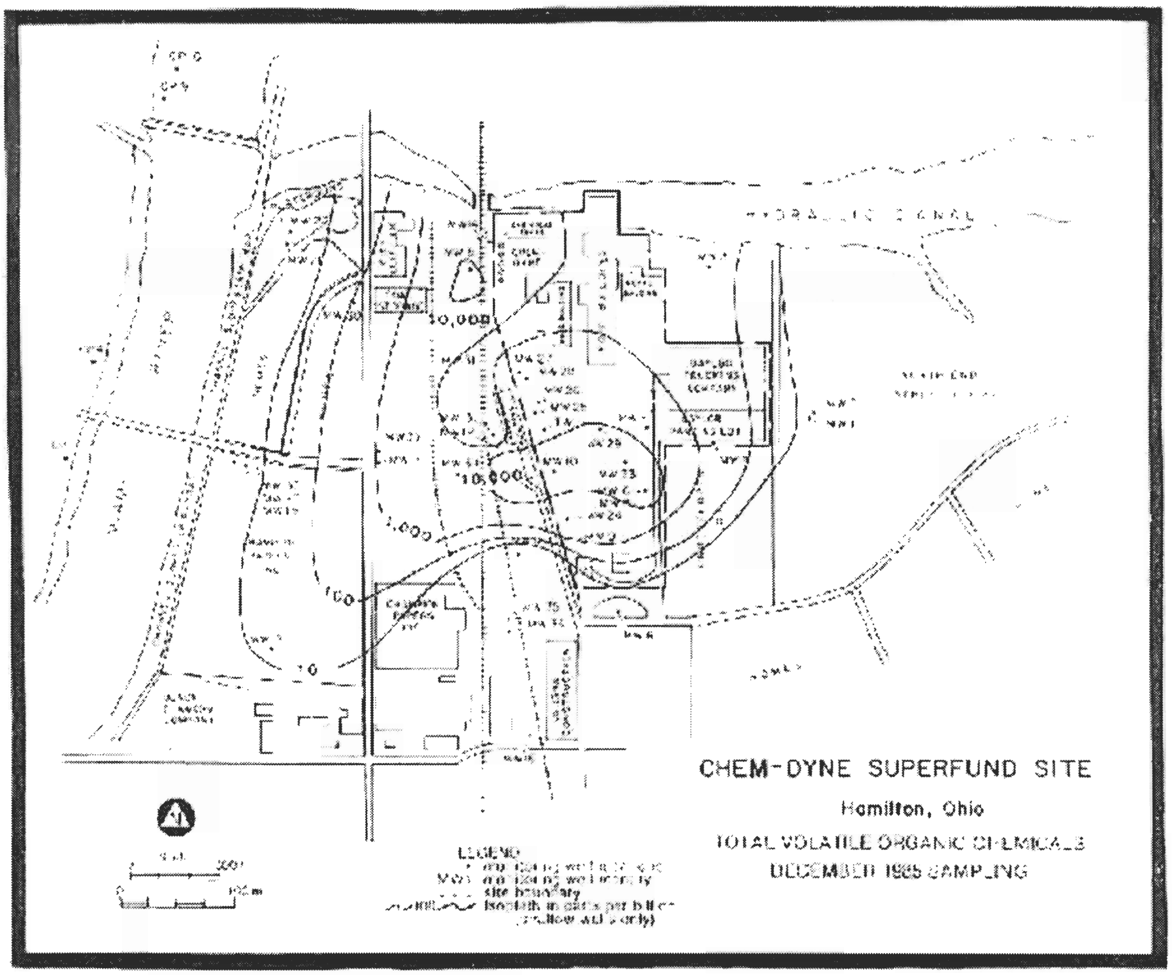


Figure 12.1 Contours of total VOC concentrations (ppb) at the Chem-/Dyne site in Hamilton, Ohio for shallow well data. December 1985 **(Source: U.S. EPA, 1989b).**

GRAPHICAL

Graphical presentation can be helpful in visualizing areal distribution of contaminants, identifying changes in water quality with time, and comparing waters of different compositions. Typical methods include, but are not limited to, bar charts, XY charts, box plots, trilinear diagrams, and stiff diagrams.

Bar Charts

Bar charts display a measured value on one axis and a category along the other. Historically, bar charts used in water quality investigations were designed to simultaneously present total solute concentrations and proportions assigned to each ionic species for one analysis or group of analyses. These charts displayed total concentrations and were based on data reported in milliequivalents per liter (meq/l) or percent meq/l. Analytes of ground water contamination studies are present as both ionic and non-ionic species and data are reported in units of mg/l or µg/l. For such studies, bar charts can be constructed to display concentrations of constituents for single or multiple monitoring wells and/or sampling events. The design and number of the charts should depend on the investigation. Figure 12.2 presents several examples of bar charts that may be useful.

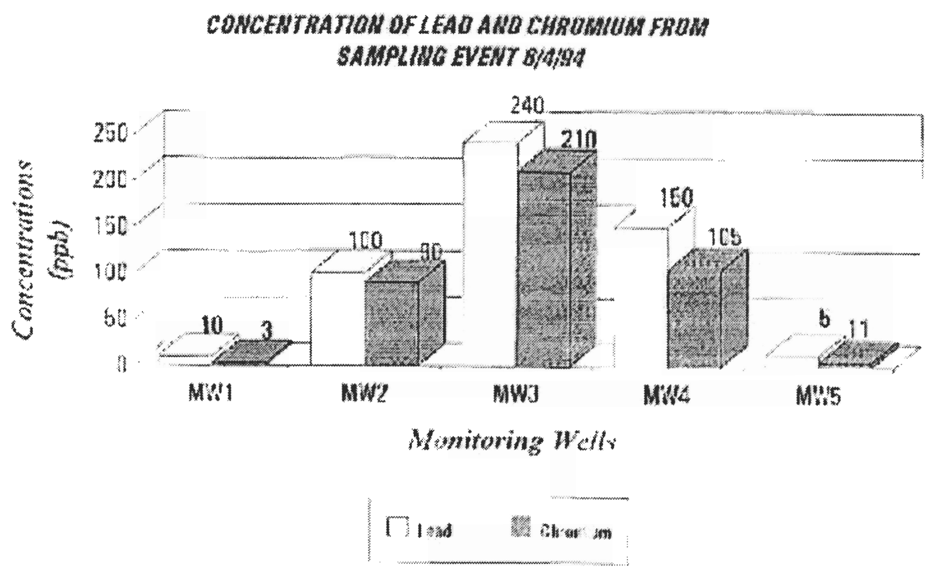
XY Charts

XY charts differ from bar charts in that both axes show measured parameters. Plots of changes in dissolved constituents with time is one example of an XY chart that is extremely useful when evaluating contaminant releases or remedial progress. Even with a relatively slow rate of flow, long-term monitoring can detect gradual changes. Time-series formats can be used to compare individual parameters for a single well with time, multiple parameters for a single well with time (Figure 12.3), or illustrate changes with time for multiple wells for a common parameter (Sara and Gibbons, 1991). It is important that care be used when evaluating data with different levels of quality assurance/quality control. Regulated entities are encouraged to supply data in graphical form showing each parameter for each well plotted against time.

Box Plots

Box plots can be used to compare ground water quality data (generally for the same parameter) between wells. The plots are constructed using the median value and the interquartile range (i.e., 25 and 75 cumulative frequency as measured central tendency and variability) (U.S. EPA, 1992a) (Figure 12.4). They are a quick and convenient way to visualize the spread of data. Complicated evaluations may dictate use of a series of plots. For example, box plots may be constructed using data from wells screened in a particular saturated unit to show horizontal changes in water quality.

(A)



(B)

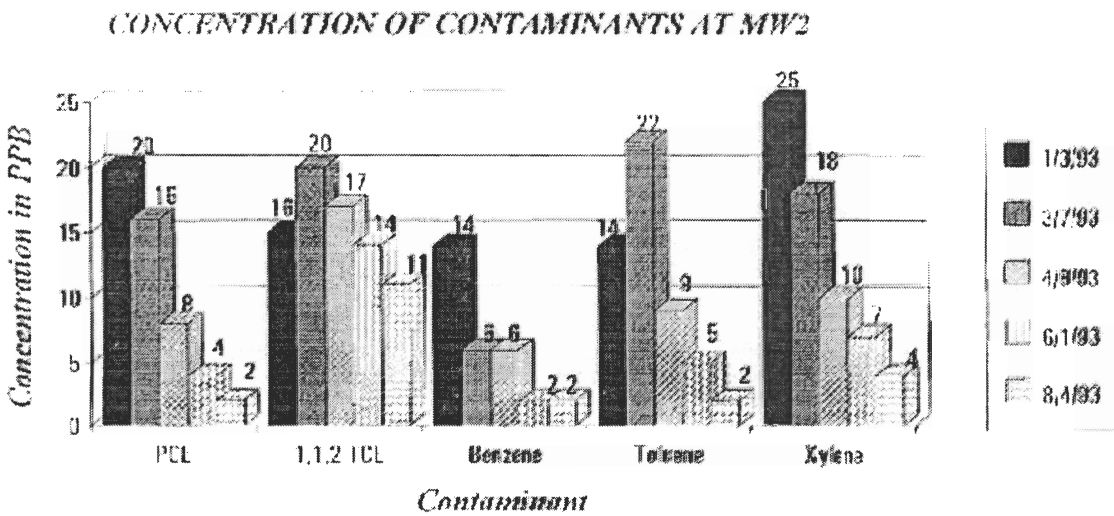


Figure 12.2 **Bar Charts. A) Shows concentrations of lead and chromium for one sampling event. B) Shows concentrations of several consituents at one well over multiple sampling events.**

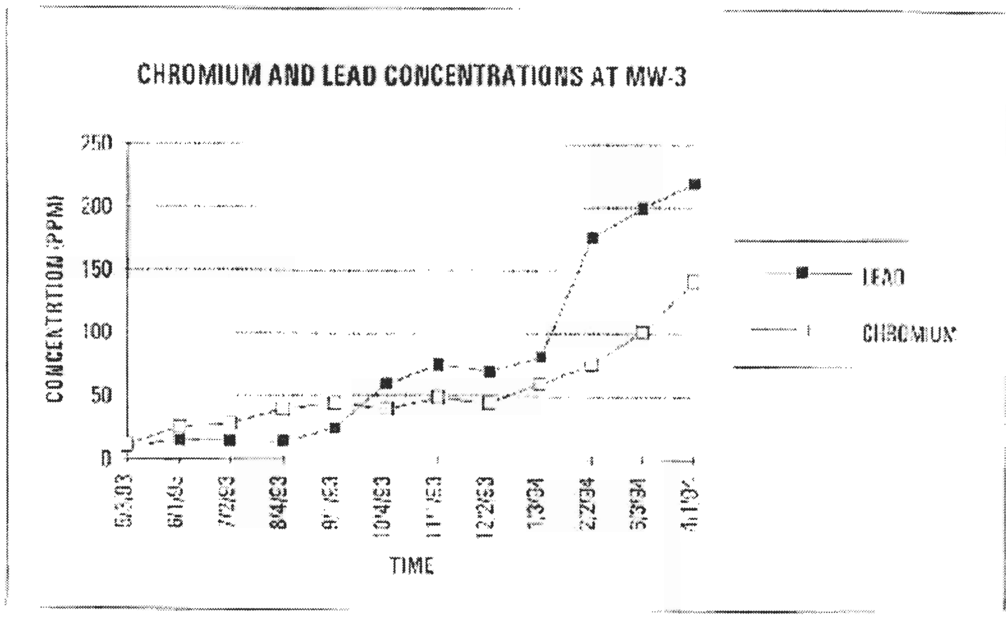


Figure 12.3 Chromium and lead concentrations over time.

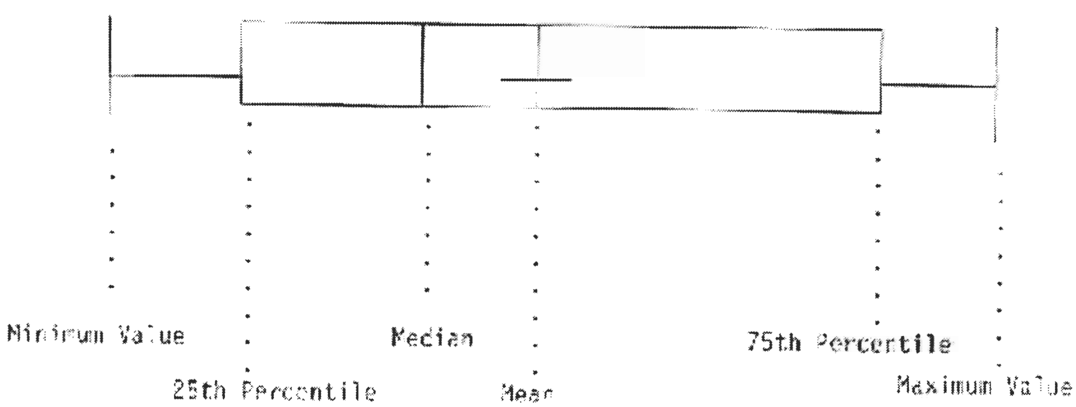


Figure 12.4 Example of a box plot

Trilinear Diagrams

Trilinear diagrams are often used in water chemistry studies to classify natural waters (Sara and Gibbons, 1991). They can show the percentage composition of three ions or groups of ions and often are in the form of two triangles bracketing a diamond-shaped plotting field (Figure 12.5). These diagrams are useful in determining the similarities and/or differences in the composition of water from specific hydrogeologic units and are convenient for displaying a large number of analyses. The diagrams may help show whether particular units are hydraulically separate or connected and whether ground water has been affected by solution or precipitation of a salt.

The value of trilinear diagrams may be limited for some investigations. Composition is represented as a percentage. Therefore, waters of very different total concentrations can show identical representation on the diagram. Because non-ionic solutes (e.g., silica and organics) are not represented (Hem, 1985), trilinear diagrams often are not used when evaluating the presence or absence of contaminants.

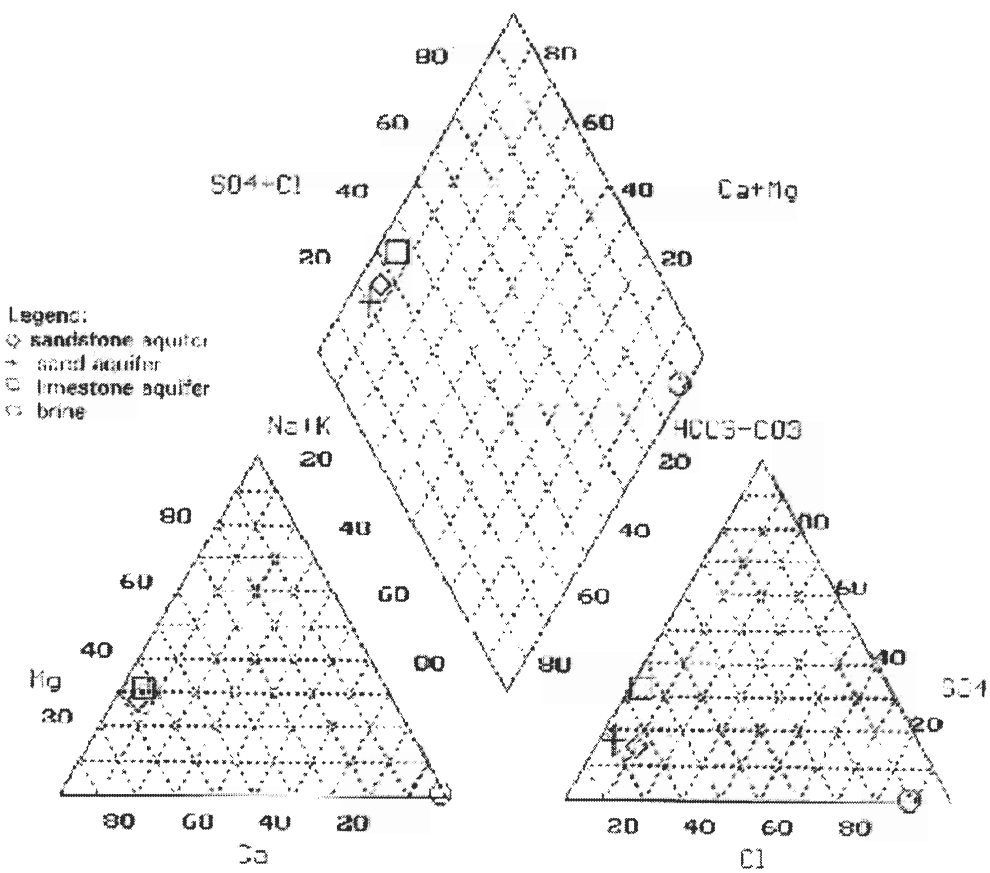


Figure 12.5 Trilnear diagram.

Stiff Diagrams

Stiff diagrams are another graphical representation of the general chemistry of water. A polygonal shape is created from four parallel horizontal axes extending on either side of a vertical axis. Cations are plotted on the left of the vertical axis and anions are plotted on the right (Fetter, 1994). The diagrams can be relatively distinctive for showing water composition differences or similarities. The width of the pattern is an approximation of total ionic strength (Hem, 1985). One feature is the tendency of a pattern to maintain its characteristic shape as the sample becomes diluted. It may be possible to trace the same types of ground water contamination from a source by studying the patterns. In the case presented in Figure 12.6, seepage of salt water from a brine disposal pit was suspected. Samples analyzed from the pit and the wells demonstrated the same pattern, showing evidence of contamination (Stiff, 1951).

STATISTICS

Ground water quality data also can be evaluated by statistical analysis. This tool can be used to compare upgradient versus downgradient or changes with time. Various regulatory programs may require use of statistics. The reader is referred to Statistical Analysis of Ground Water Monitoring Data at RCRA Facilities (U.S. EPA, 1989a), the addendum to that document (U.S. EPA, 1992b), and Chapter 13 for appropriate methodologies.

MODELING

Ground water modeling is a tool that can assist in the determination of extent and rate of contaminant migration. Models can be used throughout the investigation and remedial processes. Information on modeling can be found in Chapter 14.

DATA INTERPRETATION OBJECTIVES

The mechanism to interpret ground water quality data can vary depending on project objectives and regulatory or program requirements. Data often are evaluated to: 1) determine if a site/facility has impacted ground water (detection monitoring), 2) determine the rate, extent, and concentration of contamination (assessment monitoring), 3) determine the source of contamination, 4) gauge the effectiveness of remedial activities, and/or 5) monitor for potential health or environmental effects. Data must always be evaluated in conjunction with site hydrogeology, contaminant characteristics, and past and present land use.

IDENTIFICATION OF RELEASES TO GROUND WATER

Methods to identify whether contaminants have been released to ground water include professional judgment and statistical analysis.

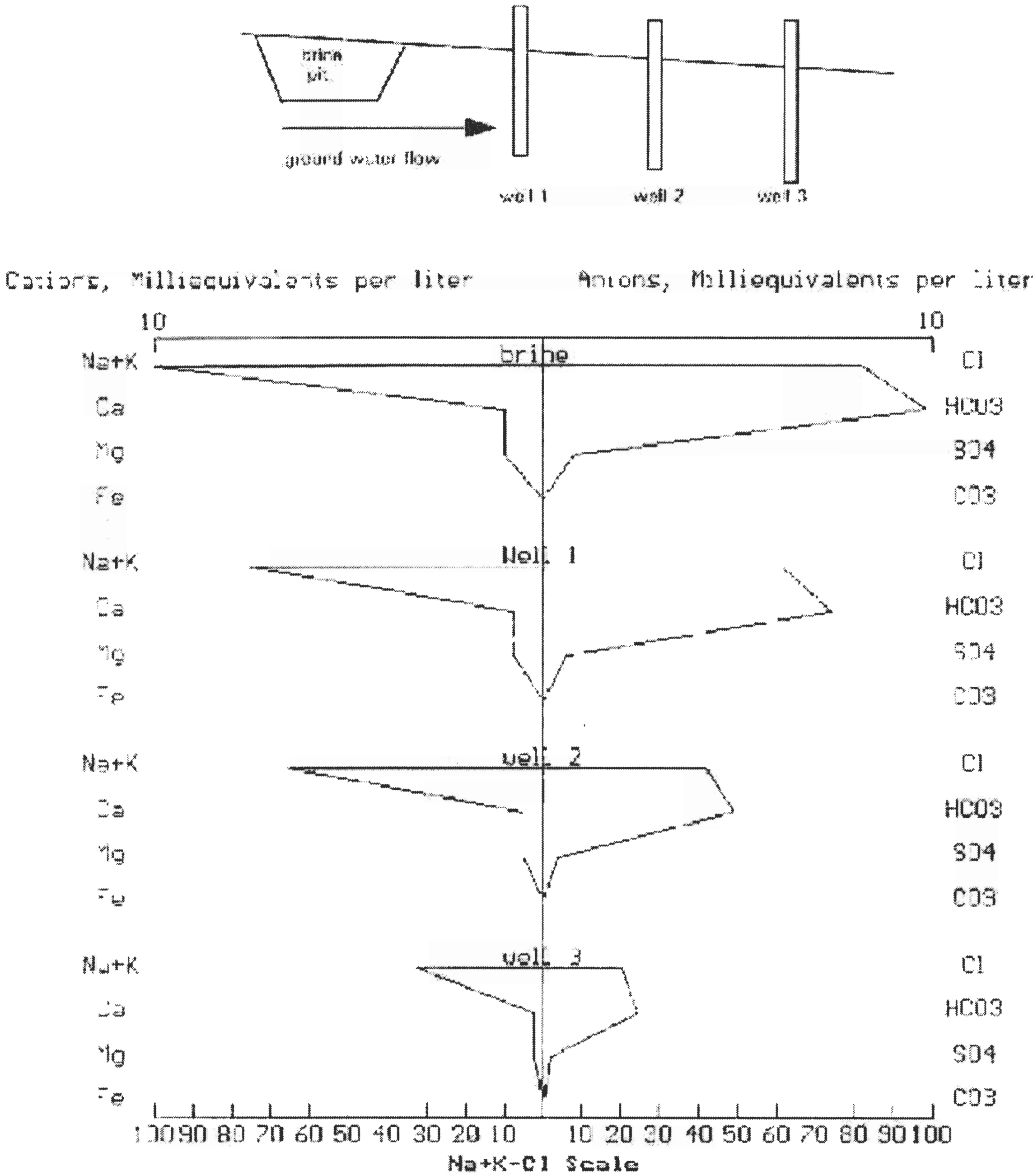


Figure 12.6 Stiff pattern demonstrating seepage of a salt from a brine disposal pit.

Professional judgment involves the use of education and experience. In some cases, a simple visual inspection of downgradient versus upgradient/background data can show obvious differences in chemical quality. The tabular and graphical presentations discussed earlier in this chapter can be used for this evaluation.

When evaluating potential ground water contamination, water quality data often are compared to primary and secondary drinking water standards. As important as it is to protect public health by identifying an exceedance, formulating a conclusion that ground water has been contaminated based solely on the exceedance is not appropriate. Certain inorganic constituents, such as iron and sulfate, can occur naturally in Ohio's ground water at levels above standards; therefore, exceedance for these constituents may not imply contamination. Conversely, values lower than a standard do not necessarily imply that contamination has not occurred. In general, the mere presence of organics, which usually are not naturally occurring, indicates contamination. Data for wells downgradient from a pollution source should be compared to data from an upgradient/background well that has not been affected by the source. If an upgradient/background well does not exist, then the results can initially be compared to known local or regional background values. However, utilization of regional values for evaluating potential contamination should be a part of initial investigations only. Further evaluation should be based on site-specific background sampling. In any ground water contamination investigation, it is essential to obtain background concentrations for chemical constituents of concern, particularly those that may be common to both the local ground water quality and the potential or known contaminant source.

Whether a release has occurred also can be evaluated by ***statistical analysis*** if adequate data are available. The U.S. EPA (1989a, 1992b) documents and Chapter 13 should be used to determine appropriate methods and application. While statistics are useful to determine if a release occurred, professional judgment still needs to be exercised to ensure that the results represent actual conditions. For example, the results may show either a "false positive" or "false negative" due to naturally occurring variations such as geologic heterogeneity and/or seasonal variability. Determining whether a release has occurred or whether the analysis has triggered a "false positive" generally requires additional investigation.

RATE OF CONTAMINANT MIGRATION

A simple and straight forward method does not exist for determining the rate of contaminant migration. In general, the rate can be estimated by a form of Darcy's Law (see Chapter 3) if it is assumed that the dissolved solute travels at the average linear ground water velocity. The rate of advancement of a dissolved contaminant can be substantially different, however. Mobility of a contaminant can be altered due to adsorption/desorption, precipitation, oxidation, and biodegradation. Mobility of a solute can be affected by the ratio of the size of the molecule to the pore size. The calculated velocity also would not account for a contaminant moving faster than the average linear velocity due to hydrodynamic dispersion. Dispersion affects all solutes, whereas[1] adsorption, chemical reactions, and biodegradation affect specific constituents at different rates. Therefore, a contaminant source that contains a number of different solutes can result in several plumes moving at different rates.

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[1] See Chapter 5 for additional explanation on how these parameters influence ground water flow paths.

The equation governing the movement of dissolved species can be developed by utilizing the conservation of mass approach. The equation in statement form, as described by Canter et al. (1988), is:

$$\boxed{\begin{array}{c}\text{Net rate of}\\ \text{change of}\\ \text{mass within}\\ \text{an elemental}\\ \text{cell}\end{array}} = \boxed{\begin{array}{c}\text{flux of solute}\\ \text{out of the}\\ \text{elemental}\\ \text{cell}\end{array}} - \boxed{\begin{array}{c}\text{flux of solute}\\ \text{into the}\\ \text{elemental}\\ \text{cell}\end{array}} \begin{array}{c}-\\+\end{array} \boxed{\begin{array}{c}\text{loss or gain}\\ \text{of solute}\\ \text{mass due}\\ \text{to reactions}\end{array}}$$

The mass of solute transported in and out of the cell is controlled by advection and dispersion. Loss or gain of solutes within the cell may be caused by chemical, biological, or adsorption/ desorption reactions. A generalized three-dimensional solute transport equation considering dispersion, advection, and reactions in a homogeneous environment takes the form as (modified from Freeze & Cherry, 1979):

$$\frac{\partial C}{\partial t} = [\frac{\partial}{\partial x}(D_x\frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(D_y\frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(D_z\frac{\partial C}{\partial z})] \qquad \textit{Dispersion}$$

$$-[\frac{\partial}{\partial x}(\overline{v_x}C) + \frac{\partial}{\partial y}(\overline{v_y}C) + \frac{\partial}{\partial z}(\overline{v_z}C)] \qquad \textit{Advection}$$

$$\pm F(c) \qquad \textit{Reaction}$$

Where:

C	=	the concentration of the polluting substance;
D_x, D_y, D_z	=	the coefficients of hydrodynamic dispersion in the x, y, z directions;
v_x, v_y, v_z	=	velocity vector components in the x, y, and z directions; and
$F(c)$	=	chemical reaction function.

Attempts to quantify contaminant transport generally rely on solving conservation of mass equations. There are essentially two kinds of models available for solving mass transport equations, analytical and semi-analytical, and numerical. Analytical models are developed by considering ideal conditions or using assumptions to simplify the governing equation. These assumptions may not allow a model to reflect conditions accurately. Additionally, even some of the simplest analytical models tend to involve complex mathematics. Numerical modeling techniques incorporate analytical equations that are so complex they necessitate use of computers capable of multiple iterations to converge on a solution (Canter et al., 1988). The numerical approach depends on tedious sensitivity analyses to develop information on the nature of the parameter interaction. Analytical models are used to verify the accuracy of numerical solutions where appropriate. Additional information on numerical, computer-oriented models can be found in Chapter 14.

EXTENT OF CONTAMINANT MIGRATION

The areal or vertical extent of contaminant plumes may range within wide extremes depending on local geologic/hydrogeologic conditions. Determination of extent generally involves sampling monitoring wells at increasing distances and depths from the source. Data for wells downgradient of the site/facility are compared to background data by visual inspection and/or statistical analysis. All downgradient locations at which significant differences are noted are considered to be within the contaminated area. The use of isopleth maps and time-series formats assist in the determination of extent. Modeling (Chapter 14) can be used to help estimate rate and extent and determine optimum locations for monitoring wells.

SOURCE OF CONTAMINATION

Ground water quality data often are evaluated to determine the source of contamination. In general, isopleth and ground water contour maps are utilized in conjunction with knowledge of area-specific geologic/hydrogeologic characteristics, contaminant properties, and past and present land use to pinpoint the source.

PROGRESS OF REMEDIATION

When gauging the effectiveness/progress of remedial action, changes in water quality can best be illustrated by time-series presentations and a series of isopleth maps prepared throughout the proceedings. The data should be compared to background or standards developed by risk assessment.

RISK ASSESSMENT

Clean-up goals often are established by means of a risk assessment. Both human health and environmental assessments can be conducted. The appropriate methodology depends on the regulatory program involved. Therefore, prior to conducting a risk assessment, the appropriate Ohio EPA Division should be consulted.

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GROUNDWATER CHEMISTRY OF SHALLOW AQUIFERS IN THE COASTAL ZONES OF COCHIN, INDIA

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Abstract. The coastal aquifers of Kerala, India experience severe degradation of water quality due to various anthropogenic activities. An attempt is made here to study the groundwater chemistry of aquifers, which lie along the coastal zone of central Kerala. Results in general indicated that the groundwaters in the shallow aquifers were found to be deteriorated. Based on Hill-Piper trilinear diagram it is confirmed that some of the dug wells were characterised by high amount of sodium and chloride (>200 mg/l) indicating the influence of saline water incursion. The presence of *E. coli* in all dug wells indicated potentially dangerous fecal contaminations, which require immediate attention. The study further raises points for the need of action for a sustainable utilization of precious resources.
Keywords. *coastal aquifer, groundwater, trilinear diagram, saline water incursion*

Introduction

Kerala, the southernmost state of India has unique hydrogeological characteristics with wide variation in the rainfall pattern (average 3107 mm). Both qualitatively and quantitatively, the coastal zones of Kerala in recent years witnessed serious groundwater problems [8, 9, 11, 24, 25]. Several studies invariably showed that water quality in the shallow aquifers situated in the coastal zone of Kerala is deteriorating alarmingly amidst plenty of water all around [1, 6, 7, 10, 12, 21, 33]. Owing to the high demand of groundwater to cater a large population in the coastal zones of Cochin, mitigation of the deterioration in the quality of groundwater in shallow coastal aquifers was initiated through groundwater recharge [30]. High population pressure, intense human activities, inappropriate resource use and absence of proper management practices leads into the deterioration. The coastal sedimentary formation serves as an excellent condition for aquifer and the average groundwater potential of this region is estimated to be more than 0.3 MCM/km [b]. In the shallow coastal aquifer, open wells are the dominant groundwater abstraction structures and the density of the open wells in the coastal area is high in the range of 400 wells/km^2 [30]. During rainy seasons, the sea becomes rough and encroaches towards land and during summer seasons the saline water finds its way through tidal channels and it admixes with shallow coast aquifers. So the qualities of water in the shallow and deeper zones become brackish [9, 20, 30].

Added up problems such as urbanisation, industrialization, unscientific landuse, lack of awareness of the people and saline intrusion all makes the quality of groundwater in Cochin coastal zone worsen. All these contribute to less recharge into the coastal aquifers thereby accentuating groundwater quality and the problem of salt water intrusion. The present investigation attempts to illustrate the scenario of groundwater quality and saline water intrusion during post monsoon (November 2003) in the coastal zones of Cochin.

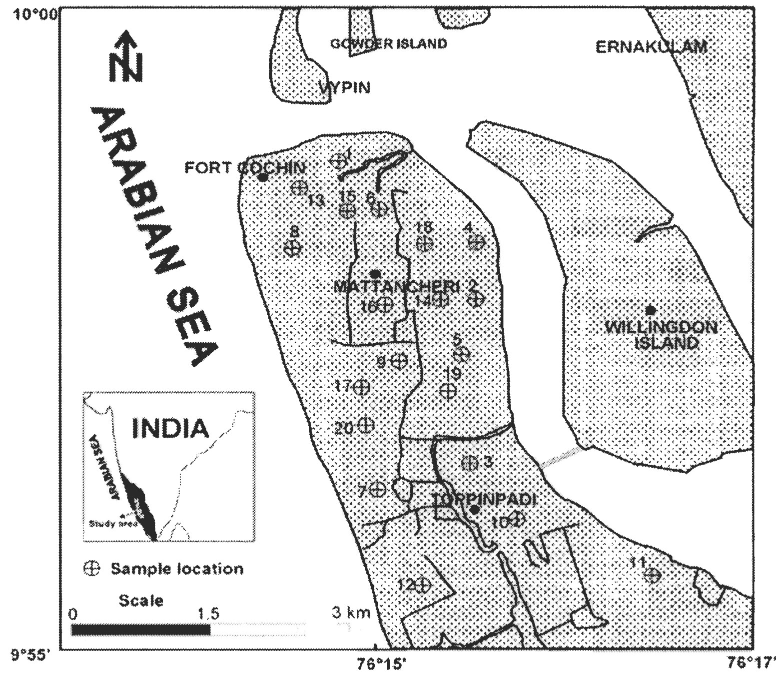

Figure 1. Base map and sample locations of the study area

Study area

The study area extends from north of Fort Cochin to the south of Thoppumpadi which lies between 9°55'–10°00'N and 76°13'–77°17'E (*Fig. 1*).

The area is bordered by Arabian Sea on west and a part of Cochin estuary in the eastern side. The area is characterised by a number of tidal channels, results into seawater encroachment, which deteriorate the water quality.

Exploratory borehole study conducted by Central Groundwater Board indicates the recent coastal alluvium followed by Tertiary sediments consists of two distinct formations. The upper most formation is Warkalais with thickness of nearly 80 m underlined by thick sequences of sediments called Vaikom beds. The Tertiary sedimentary formation of Kerala basin unconformably overlays Precambrians. In the present study most of the dug wells are tapping groundwater at depth ranging 2 to 8 m fall in recent coastal alluvium [29].

Data and methodology

Groundwater samples have been collected from 20 dug wells during post monsoon (November 2003) at stations as shown in *Fig. 1*. The pH was measured at the spot, whereas the concentration of major cations, anions and *E. coli* were analysed at the laboratory as per the standard analytical procedures [2, 14].

Sodium and potassium in groundwater samples were analysed using Flamephotometer (Systronics FPM digital model). Calcium and magnesium were estimated by EDTA titri metric method, whereas chloride was determined by argentometric titration using standard silver nitrate as reagent. Carbonate and bicarbonate concentrations of the groundwater were determined titrimetrically [2, 14]. Sulphate concentration was carried out following turbidity method using double beam UV-Visible spectrophotometer

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(Hitachi Model 2000) [2]. The microbiological quality of samples were analysed in terms of most probable number (MPN) of faecal coliforms using lactose broth and incubation at 44.5 °C. Tubes showing positive results after 24 to 48 hours of incubation were streaked on to Mac Conkey Agar and esoine methyl blue (EMB) agar and incubated at 37 °C for 24 to 48 hours. Typical *E. coli*-like colonies were isolated and confirmed biochemically as *E. coli* using IMViC test. The number was expressed as MPN index / 100 ml.

Results and discussion

Table 1 presents the results of groundwater analysis.

pH

The pH values of groundwater were varied from 7.01 to 8.2 indicating slightly alkaline nature. Groundwaters with pH value above 10 are exceptional and may reflect contamination by strong base such as NaOH and $Ca(OH)_2$ [22]. The range of desirable limit of pH of water prescribed for drinking purpose by ISI [27] and WHO [35] is 6.5–8.5 while that of EEC [23] is 6.5–9.0.

The analysed groundwater samples are within the limit prescribed by ISI [17], WHO [35] and EEC [23]. There is no much distinct variation of pH in the different wells selected for the present study, indicating that the groundwater is tapping from aquifers of a single formation. The slight alkaline nature of groundwater may be due to the presence of fine aquifer sediments mixed with clay and mud, which are unable to flush off the salts during the monsoon rain and hence retained longer on other seasons.

***Table 1.**: Chemical and E. coli analysis data of groundwater*

well no.	pH	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	CO_3^{2-} and HCO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	MPN index FC / 100 ml
1	8.08	380.7	23.5	57.9	20.2	200.2	470.4	1.8	150
2	7.61	145.7	90.6	102.1	12.0	317.8	145.2	2.1	290
3	8.01	480.4	110.0	190.4	22.7	334.1	749.4	5.6	95
4	7.67	457.1	75.2	117.7	10.3	321.9	640.3	2.4	95
5	7.10	120.0	18.2	72.9	22.5	352.4	36.1	1.8	460
6	7.14	110.9	19.8	74.1	26.5	310.1	63.5	2.2	290
7	8.20	546.0	72.2	122.0	11.2	276.9	757.4	3.8	93
8	7.26	90.7	30.2	52.8	5.0	179.7	96.7	2.2	460
9	7.30	70.6	38.4	48.8	4.8	187.0	49.8	1.1	460
10	7.36	445.9	45.9	70.2	11.0	160.1	612.0	3.4	120
11	7.53	110.6	38.3	50.8	15.3	203.6	128.2	2.5	240
12	7.60	339.0	95.1	87.0	22.8	187.4	541.6	3.5	150
13	7.57	111.5	65.2	54.4	3.6	185.7	126.0	1.9	210
14	7.20	65.0	23.7	82.6	3.5	238.5	23.7	0.9	240
15	7.67	85.3	42.5	97.1	2.5	234.0	70.6	2.1	210
16	7.54	64.5	15.2	61.4	1.2	167.4	37.5	0.8	460
17	7.50	34.0	8.9	24.6	2.3	77.0	23.1	0.6	290
18	7.07	20.1	10.2	25.6	1.7	62.5	26.0	1.2	460
19	7.50	48.5	27.6	83.2	10.1	202.2	55.4	1.3	240
20	7.01	11.7	5.2	34.0	8.9	74.1	25.2	0.9	460

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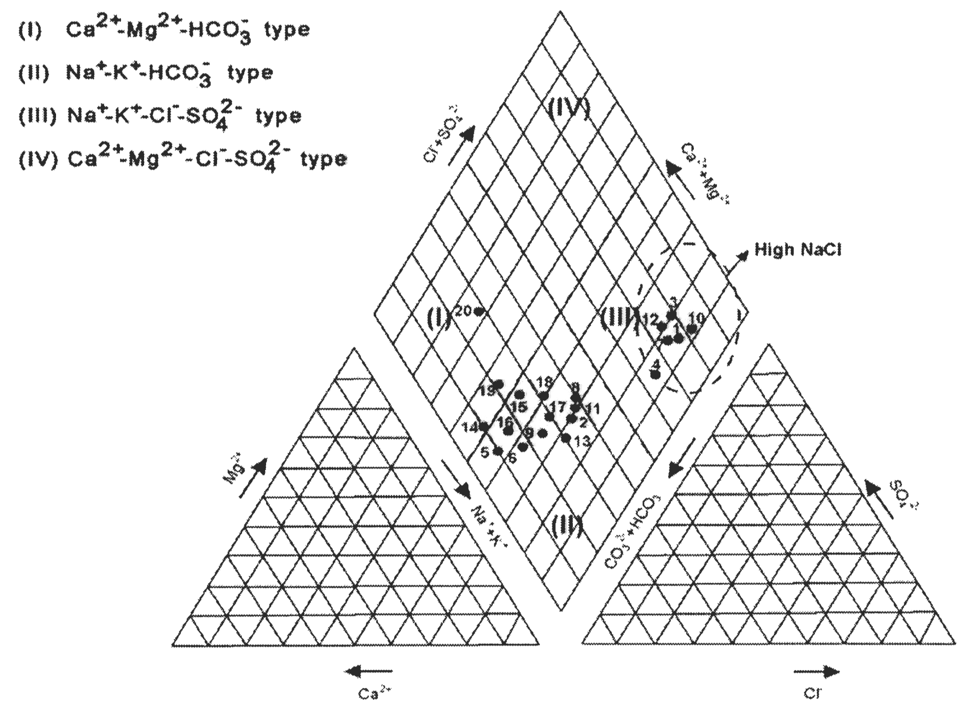

***Figure 2.**: Trilinear diagram of dugwell samples*

Major cations and anions

Major cations and anions such as Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^{2-}, SO_4^{2-} and Cl^- (*Table 1*) were plotted in hydrochemical trilinear diagram. In general high concentrations of chloride in groundwater is attributed to rainwater, seawater, natural brines, evaporate deposits and pollution [18, 19]. In dug wells (Nos. 1, 3, 4, 7, 10 and 12) high concentrations of chloride and sodium were measured. This high concentration can be due to the proximity of the wells to the tidal channel and the poor muddy sediments present in the aquifer system which further infers saline incursion. The high chloride content is generally taken as an index of impurity of groundwater. The clogging nature of sediments permit only intermittent flushing and hence the impurity (sodium and chloride) was sustained longer as compared to other wells. The dug wells (Nos. 1, 3, 4, 7, 10 and 12) had higher values, which were above the permissible limit of 250 mg/l [17, 23, 35]. Sulphate concentration in groundwater of coastal zone were within the permissible values recommended by WHO [35], EEC [23] and ISI [17]. The major cations and anions were further analysed based on Hill-Piper trilinear diagram.

Hill-Piper diagram

Pattern diagram was initially conceived by Hill [16] and later improved by Piper [27] and the detailed analysis of Hill-Piper trilinear diagram for post monsoon season (*Fig. 2*) is explained below using facies diagram.

The hydrochemical pattern diagram helps in hydrogeochemical facies classification [5]. The trilinear diagram of this study is classified into four hydrochemical facies based on the dominance of different cations and anions: facies 1: Ca^{2+}-Mg^{2+}-HCO_3^- type I; facies 2: Na^+-K^+-Ca^{2+}-HCO_3^- type II; facies 3: Na^+-K^+-Cl^--SO_4^{2-} type III and facies 4: Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-} type IV.

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Fig. 2 shows that the majority of samples were in type II (Na^+-K^+-Ca^{2+}-HCO_3^-) followed by type III (Na^+-K^+-Cl^--SO_4^{2-}) and type I (Ca^{2+}-Mg^{2+}-HCO_3^-). This indicates that post monsoon samples are enriched with sodium, bicarbonate and chloride types and, from this it is evident that sea water and tidal channel/canals plays a major role in controlling the groundwater chemical composition in the coastal shallow aquifer, which consists of recent alluvium. Nageswara [26] conducted study on groundwater salinity of the shallow aquifers in the central Kerala and inferred that salt-water encroachment into shallow aquifers can be minimised by construction of tidal barriers. The removal of sodium ions from seawater which has infiltered into fresh water aquifer has been described by a number of workers by the method of ion exchange [28, 31]. Sodium ion present in seawater will exchange to Ca^{2+} ions. The conversion of calcium bicarbonated water to sodium bicarbonate water in many aquifers is also undoubtedly due to ion exchange [4, 13]. The freshwater will change into $NaHCO_3$ type water [3]. Further, the trilinear diagram (*Fig. 2*) revealed that dug wells (Nos. 1, 3, 4, 7, 10 and 12) falling in facies 3 showed the saline water intrusion of coastal aquifers with high percentage of sodium and chloride.

Escherichia coli

The bacteriological content is one of the most important aspects in drinking water quality. The most common and widespread health risk associated with drinking water is the bacterial contamination caused either directly or indirectly by human or animal excreta. *E. coli*, a typical fecal coliform is selected as an indicator of fecal contamination. The present study revealed a high incidence of fecal coliform, which ranged 93 to 460 MPN index FC / 100 ml (*Table 1*), indicating poor sanitary condition and improper waste disposal. The seepage of *E. coli* is easier in the sedimentary formation compared to hard rock terrains [15], which supported the present study. The fecal contamination is mainly due to improper solid waste disposal from farmyard into the soak pits located very near to drinking water wells, which do not have any protecting wall [34]. According to Woods [34], effluents from point-like sources such as septic tanks and general farmyard wastes are considered as the main sources of contamination of groundwater. The lack of protecting walls will lead to the entry of contaminated runoff water into the well from the upstream. Rojas *et al.* [32] have studied the contamination of the waters of River Rimac, Peru, and the adjoining groundwater and found that the cause of pollution is due to mining and agricultural activities as well as domestic fecal pollution upstream. The presence of *E. coli* in groundwater indicates potentially dangerous situation, and requires immediate attention.

Conclusion

Analysis of groundwater samples from the study area indicated signs of deterioration, which highlights the need for a sustainable utilization of precious resources. Groundwaters present in the shallow aquifers of some of the stations were poor in quality and beyond potable limit as per the standard set by WHO and ISI. Samples from rest of these zones indicated that the groundwater quality is satisfactory (geochemically) but requires attention, with a thrust on proper sanitation and waste disposal of the adjacent coastal region. The groundwater collected from the six dug wells indicated that there is a mixing of fresh and saline water during post monsoon. The study revealed that these wells need more controlled withdrawal of water with more recharging in order to maintain fresh-saline water equilibrium. Further, it stressed that the coastal zone of the study area need more attention in order to maintain the ground water quality. The study also recommends the necessity of proper sanitation and waste disposal to sustain the groundwater quality.

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Evaluation of Aquifer Contamination from Salt Water Disposal Wells

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In the United States an estimated 140,000 Class II wells for salt water disposal and enhanced hydrocarbon recovery are presently injecting some 30 million barrels of brine per day into subsurface formations. While no systematic survey has documented the extent of shallow ground water contamination from these disposal practices, it is recognized as a major potential pollution source in leading hydrocarbon-producing states. The reliability of impact assessment calculations required under Underground Injection Control permit regulations for Class II wells can be improved by the correct application of existing techniques in predicting individual system operational performance. Modifications to some of these technical indicators include: (a) estimates of radius of endangering influence that require observed initial hydrostatic heads and aquifer hydraulic transmitting properties for the injection interval; and (b) the geochemical characterization of nearby suspected shallow ground water contamination using all major ion concentrations in a trilinear diagram, instead of using only chloride as a brine tracer. A field application demonstrates the relative importance of these and other techniques in characterizing shallow ground water contamination from a salt water disposal well in Oklahoma.

INTRODUCTION

Since the first U.S. hydrocarbon production wells were drilled in Pennsylvania in 1859, between 2.2 and 2.7 million additional wells have been completed. Approximately two million of these have been abandoned, and 140,000 converted to Class II (22) saltwater disposal (SWD) or enhanced recovery wells. Most of this activity is concentrated in the major hydrocarbon-producing states: Texas, Louisiana, Oklahoma, New Mexico, Kansas, Alaska, California, and Wyoming. It has been estimated that over 30 million barrels (one barrel equals 42 U.S. gallons) of brine per day are injected into the subsurface. While no systematic survey has been completed to determine the extent of shallow ground water pollution resulting from these disposal practices, this salt water is recognized as perhaps the largest single potential contaminant of potable subsurface waters.

Possible pathways for the underground migration of injection fluids have been discussed by Canter (3), the Environmental Protection Agency (21), and Fryberger and Tinlin (8). These include: (a) corroded or improperly plugged injection wells where the intended receiving interval or adjacent saline aquifers are not hydraulically isolated from freshwater geological horizons; (b) abandoned exploration wells located within the radius of endangering influence created from nearby active or recently active injection wells; (c) natural or artificially induced fracturing of geologic units resulting in the hydraulic interconnection of the injection horizon, adjacent saline aquifers, and/or freshwater aquifers; or (d) various combinations of the above. While the resulting contamination of freshwater aquifers is easily discernible long before toxic concentration levels are reached, the injection sources can render vast quantities of ground water resources useless for municipal, industrial, or irrigation purposes over prolonged periods. Once an aquifer is contaminated, these chloride-rich brines are not easily or inexpensively removed.

One might surmise that recent Federal and state regulations governing subsurface brine disposal would be sufficient to control these operations. While such efforts are commendable, some serious deficiencies still persist, as will be explained below.

ASSESSMENT TECHNIQUES

Management and regulatory review personnel have a number of proven technical indicators to predict performance of newly proposed injection well operations or to assess the contamination suspected of being associated with an existing well. These tools have evolved from the petroleum, subsurface hydrology, and geochemistry disciplines. The most useful of these include: (a) calculations of radius of endangering influence; (b) piezometric head contour maps; (c) formation hydraulic transmitting properties; and (d) water quality analyses using trilinear diagramming of major ion parameters. Each of these is briefly described below. A field application further illustrates their relative usefulness.

Techniques describing the computation of the radius of endangering influence have been summarized by Warner et al. (23). While several complex situations are considered in their analyses, insufficiency of subsurface data severely limit routine applications of all but one procedure. This case is equivalent to the Cooper-Jacob (4) method commonly employed in water well hydraulics, and is a special case of the Theis (19) nonequilibrium equation applicable at relatively late times or small distances from the injection well. The Cooper-Jacob equation is generally written as

$$s = Q/4\pi T \ln (2.25\ Tt/r^2S) \qquad (1)$$

where ln denotes the natural logarithm; s is the upconing piezometric head in the receiving interval at radius r in response to injection (measured as a vertical distance above the hydrostatic fluid level in the injection horizon); Q is a constant injection rate (volume per unit time); T and S are the injection interval hydraulic transmitting properties of transmissivity (length squared per unit time), and storage coefficient (dimensionless), respectively; t is time after injection begins; and r is the radial distance from the injection well. In Eq. 1 any consistent system of units may be used. A similar equation was developed by Mathews and Russell (14), and is listed by Warner et al. (23) as their Equation 4; however, these equations utilize a mixed system of oil-field units.

The criterion for using Eq. 1 instead of the Theis equation is that u be less than 0.01, where $u = r^2S/4Tt$. The percent relative error (RE) introduced into Eq. 1 can be computed from

$$RE = [w - W(u)] * 100/\ W(u) \qquad (2)$$

where w equals the natural logarithmic term in Eq. 1, and $W(u)$ is the Theis well function corresponding to the value of u. Tables for $W(u)$ have been computed (6), and are commonly summarized in most ground water textbooks.

In actual application Eq. 1 should be modified to incorporate

$$h = H + s \qquad (3)$$

where H is the initial undisturbed piezometric head in the receiving horizon prior to any injection and is measured as the vertical elevation to any convenient horizontal reference datum; s is given by Eq. 1; and h is the total predicted piezometric head at radius r. The radius of endangering influence (R) is defined as the radius $r = R$ where h is equal to the datum-referenced piezometric head in the lowest freshwater aquifer overlying the injection interval. Normally this piezometric surface is unknown, so R is more commonly defined as the radius where h is equal to the datum elevation of the base of the lowest freshwater aquifer. Anywhere inside this radius, the injection zone has a sufficiently large piezometric head that fluids can physically migrate vertically upward into the lowest freshwater aquifer if a permeable conduit exists. If H is unknown then these calculations are subject to large errors. Warner et al. (23, p. 8) imply that in these situations H should be set equal to the injection interval hydrostatic head resulting from the entire saturated thickness of the overlying rock. If one assumes that this saturated thickness is located somewhere between the top and bottom of the lowest freshwater aquifer, then Eq. 3 can often yield an R greater than 10,000 feet. When H is below the base of the lowest freshwater aquifer, then smaller R values are expected. Finally, if H is near the top of the deep injection zone, then this zone is said to be accepting fluids under a vacuum and R will approach zero for shallow freshwater aquifer situations.

Under the current Underground Injection Control (UIC) program guidelines established by the Safe Drinking Water Act of 1974, these calculations may be used to establish the zone of influence, or R may be set at some minimum fixed distance. In Oklahoma the Oil and Gas Conservation

Division of the Corporation Commission maintains jurisdiction of the UIC program for Class II wells, requiring new injection well permit applicants to perform only the first part of the above calculations. They do not require that any hydrostatic fluid levels in receiving intervals be established before injection begins, nor do they require any periodic measurements of h to be reported during system operation. Furthermore, no physical measurements for T and S, or their petroleum equivalent parameters, are required in support of radius of endangering influence calculations. Hence, large errors in R can be routinely anticipated. To complicate matters even further, abandoned exploration or production wells are often located within 660 feet of injection wells. These abandoned wells were usually plugged in compliance with the existing regulations of the day, but such plugging is commonly inadequate by current standards. Other states have varying requirements within the framework of Federal regulations. For example, Texas currently sets the radius of influence at a minimum of 1320 feet.

Water level measurements from spatially distributed wells that are completed into the same hydrogeological horizon can be used to construct piezometric contour maps. This routine technique of ground water flow analysis is one of the fundamental models that hydrologists use to characterize subsurface fluid environments. A minimum of three wells is required to establish a preliminary two-dimensional (2-D) estimate of subsurface flow direction for a given hydrogeologic unit. Additional well data will allow the construction of a 2-D piezometric contour map. Techniques for construction can be found in any introductory text. The contour map should be based on data collected at approximately the same time. Surface elevations can be estimated from topographic maps, but a physical survey from a known benchmark is the preferred technique if only small differences in water levels are encountered. If measurements or estimates of hydraulic conductivity and effective porosity are available, then the 2-D ground water flow velocity can be inferred from the piezometric map by using Darcy's law. These velocity estimates can yield travel times between the contaminant source and suspected point of contamination. Extension of this technique to 3-D flow fields is straightforward, but requires substantially more physical observation.

Verification of integrity of the injection well isolation between the brine and freshwater aquifers can be accomplished via water quality analyses. If concentration levels of major ions (i.e., sodium, potassium, calcium, magnesium, chloride, sulfate, bicarbonate, and carbonate) are available from the same wells used to construct the piezometric map, then a geochemical characterization of ground waters can be made. These concentrations are routinely reported in milligrams per liter (mg/L). Conversion to milliequivalents per liter allows one to compute a simple cation-anion balance, and to graphically represent water quality analyses on a trilinear diagram. Details can be found in Todd (20) or Freeze and Cherry (7). The trilinear diagram was originally developed by Piper (16); a microcomputer program written in HP-BASIC for automated plotting was presented by Morris et al. (15). In Oklahoma this technique is not commonly used in practice since unreported bicarbonate analyses are not directly associated with brine contamination. Routine analyses are vital, however, since bicarbonate concentrations reflect the degree of atmospheric and vadose zone fluid interconnection to ground water supplies. Brines are typically low in bicarbonate and high in chloride; uncontaminated shallow ground waters will usually show the reverse. Through trilinear diagram plotting, these and other differences in major ion compositions will become readily apparent. Furthermore, the concepts of a model with two- or three-end-member mixing can often help to explain contamination of shallow ground waters by oil field brines, especially when used in conjunction with the previous techniques presented above. The example given below illustrates this point.

CASE HISTORY: DEVORE SWD WELL

In 1948 the DeVore No. 1 hydrocarbon exploration well was completed in the NE, SE, NW of Section 2, T21N, R2W, Noble County, Northcentral Oklahoma. Shortly thereafter it was abandoned as a dry hole, and was subsequently converted to a salt water disposal well. It has operated almost continuously since then under several different owners; corroded injection tubing and packers were repaired in late 1984. This well is currently permitted to inject up to 400 barrels of salt water per day, at an injection pressure not to exceed 300 pounds per square inch gage (psig). Similar operational conditions have apparently existed since the early 1950s.

Within and surrounding the well site, only a thin veneer of soils have developed. Surface sedimentary rock exposures have been identified as four unnamed units within the Wellington Formation of the Permian System (1,11, 17). The DeVore SWD well is located within the uppermost of these four units. The most striking features of these Wellington sequences of sandstones and mudstones are the dominant red color, and frequent facies changes where lenticular sandstones laterally grade into red mudrock and thin dolomites. Salt-bearing sequences of Permian age are noticeably absent from surface and near-surface horizons in this area of Oklahoma (12). Sandstones within this upper unit of the Wellington Formation reflect an average paleocurrent direction of North 5 degrees East (N5E), with secondary directions as both west and east. Shelton et al. (17) also report orthogonal joint-strike frequency directions of N45W and N50E, which are associated with faulted anticlinal structures in the western third of Noble County, including the DeVore well site.

During October, 1984, the Oil and Gas Division of the Oklahoma Corporation Commission directed the current owner to install four shallow monitoring wells around the SWD well because of suspected ground water contamination. These were completed in November, and sampled several times during 1985. Figure 1 shows these well locations with respect to the SWD well. Each of these PVC-cased wells penetrates 25 to 62 feet of red mudstone within the Wellington Formation before encountering a four- to eight-foot sandstone layer of continuous areal extent. Hydraulic conductivities for each monitor well were obtained using the in-situ technique of Bouwer and Rice (2). These values range from 5 to 25 feet per day, and represent essentially horizontal permeability.

Only four water level measurements from the shallow sandstone were available to construct the piezometric contour map depicted in Figure 1. These measurements were supplemented by three surface stream elevations taken from locations where this same sandstone horizon outcrops in the unnamed tributary stream channel located west of the SWD well, and five additional surface stream elevations. As such, these twelve data points form the basis of the piezometric contour map, and represent the best available picture of shallow subsurface hydraulic conditions within the sandstone zone. With this piezometric map and the measured hydraulic conductivity values, the ground water near the SWD well is computed to have a flow velocity of about 180 feet per year, oriented at approximately N60W. This calculation is based upon Darcy's law with a geometric mean hydraulic conductivity of 6.4 feet per day, an assumed sandstone thickness of 10 feet, an effective porosity of 0.25, and an anisotropy ratio of two in aquifer transmissivity, with the major axis oriented east-west. The ten-foot thickness value represents a conservative approximation to the reported four- to

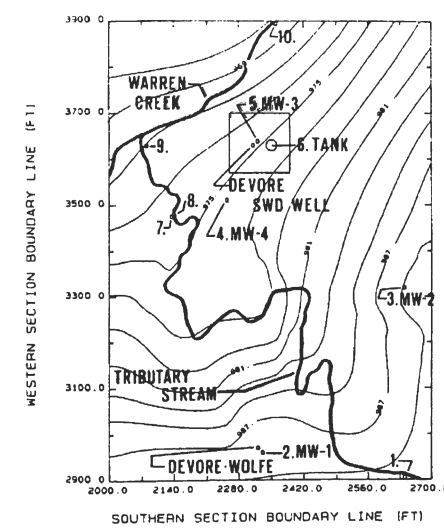

FIGURE 1. Piezometric map for the sandstone unit, showing sequentially numbered surface and ground water sampling points. Monitor wells are designated as MW-1 to MW-4. Contour from 967 to 989 ft at 2 ft intervals.

eight-foot values from the monitor well drilling logs, whereas the 0.25 porosity value is typical of sandstone. The assumed anisotropy ratio is subjectively based upon paleocurrent orientation values reported in Shelton et al. (17), and the observed surface drainage pattern near the SWD well. The magnitude of the computed ground water flow velocity is not overly sensitive to an order of magnitude change in the anisotropy ratio. For example, if the value of the minor axis transmissivity is reduced by a factor of ten, the resultant velocity decreases to 160 feet per year; however, the predicted average flow direction would be almost due west. If the original major transmissivity axis were shifted to a north-south orientation, then the predicted flow direction would be about N25W, at about 190 feet per year

According to Bingham (in 17) the shallow ground water within Noble County is of only fair quality. Only limited historical water quality analyses are available from wells in Noble County. The total dissolved solids (TDS) concentration of samples reported by Shelton et al. (17) ranges from 522 to 1160 mg/L. Bingham and Bergman (1), however, report that TDS ranges from 60 to 4610 mg/L with concentration of 500 to 2000 mg/L more typical. Ground waters containing 2000 to 4600 mg/L TDS are generally limited to small local areas, and probably could be traced to local oil and gas drilling or production activities. Numerous shallow wells in the Wellington Formation yield water with TDS concentrations between 60 and 500 mg/L. Examination of the Oklahoma Water Resources Board water quality data base (J. Black, pers. comm., May, 1985) confirms these general observations. On June 14, 1985, the TDS levels of shallow ground water at the DeVore site ranged from a low of 848 mg/L in PVC well MW-2, to a high of 196,000 mg/L in PVC well MW-3. The DeVore injection well showed a TDS level of 257,000 mg/L. Similar levels have existed since early February, 1985, when these same wells were first sampled.

The historical water quality analyses reported by Shelton et al. (17) are depicted on the trilinear diagram of Figure 2. In this diagram major water quality parameters are plotted as percentages of total milliequivalents per liter so that chemical similarities or differences are more readily discernible. More detailed explanations and alternate graphical representations are available (9,13,16,18). The historical data presented in Figure 2 may be viewed as an approximate background snapshot of average quality shallow ground water within Noble County, and can be used as a basis for comparison of water samples collected from other locations.

In June of 1985 ten water samples were collected for detailed laboratory analyses from ground and surface sampling points surrounding the DeVore well site. Four of these samples were from the PVC monitor wells, one was from the DeVore injection well fiberglass storage tank, and five were from nearby streams. All of these sample points are shown in Figure 1; Figure 2 shows results of the respective analyses on the trilinear diagram. This graph shows that major ion levels for samples recovered from PVC monitor wells MW-3 and MW-4 (samples 4 and 5) are geochemically identical to the DeVore injection well waters (sample 6). In addition, stream samples 8 and 9 are geochemically similar to injection waters, showing some minor dilution from uncontaminated surface waters. This graphical representation indicates that the DeVore SWD well has contaminated the surrounding shallow ground water and the unnamed tributary stream lying to the immediate west of the SWD well. This conclusion is further supported by the piezometric contour map in Figure 1, and by the fact that no other source area is located sufficiently near the site which could account for the abnormally high contaminant levels observed at MW-3 and MW-4. Figure 3 shows other oil and gas exploration wells drilled within Section 2, T21N, R2W, and clearly illustrates this point.

The sample from well MW-2 (sample 3) appears to be chemically similar to historical ground water samples obtained from unrelated sites in Noble County (see the lettered points in Figure 2), and to surface sample 1. These samples reflect uncontaminated waters and can be used for background comparison purposes. Surface samples 7 and 10 appear to be somewhat

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S6
DATE 2/14/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	7	60	0.06	0.143	0.01 *
0.50	0.25	7	60	0.06	0.143	0.01 *
0.75	0.00	0	60	0.00	0.000	0.00
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.02

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S8
DATE 2/14/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.50	0.40	6	60	0.20	0.127	0.03 *
1.00	0.40	6	60	0.20	0.127	0.03 *
1.50	0.50	6	60	0.25	0.127	0.03 *
2.00	0.00	0	60	0.00	0.000	0.00
2.25	0.00	0	60	0.00	0.000	0.00
2.25			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.08

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S9
DATE 2/14/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.30	4	60	0.08	0.095	0.01 *
0.50	0.25	4	60	0.06	0.095	0.01 *
0.75	0.00	0	60			
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.01

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S10
DATE 2/14/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.00	0.00	0	60	0.00	0.000	0.00
0.25	0.25	16	60	0.06	0.287	0.02
0.50	0.35	22	60	0.09	0.383	0.03
0.75	0.30	22	60	0.04	0.383	0.01
0.75			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.07

* Flow velocity below limits of meter.

PUBLIC SERVICE COMPANY OF NEW MEXICO
SAN JUAN GENERATING STATION

SHUMWAY ARROYO DISCHARGE RATE MEASUREMENTS

SITE S11
DATE 2/14/2006
TECHNICIAN

TAPE (ft)	DEPTH (ft)	COUNT (clicks)	TIME (sec)	AREA (sq ft)	VELOCTY (fps)	DISCHARGE (cfs)
0.0	0	0	60	0.00	0.000	0.00
0.5	0.5	25	60	0.25	0.431	0.11
1.0	0.5	25	60	0.25	0.431	0.11
1.5	0.5	20	60	0.25	0.351	0.09
2.0	0.4	18	60	0.20	0.319	0.06
2.5	0.4	18	60	0.20	0.319	0.06
3.0	0	0	60	0.00	0.000	0.00
3.0			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			
			60			

TOTAL Q 0.43

* Flow velocity below limits of meter.

APPENDIX B

QAL-1
3/7/2006
GROUNG WATER QUALITY
TRI-LINEAR DIAGRAM

ION	mg/l	Factor	meq/l	%
Sodium	1300	23.0	56.5	51.8
Magnesium	360	12.2	29.5	27.0
Potasium	32.8	39.1	0.8	0.8
Calcium	448	20.1	22.3	20.4
			109.2	100.0
Chloride	316	35.5	8.9	6.5
Sulfate (SO4)	5800	48.0	120.8	88.3
HCO3 as CaCO3	358	50.0	7.2	5.2
HCO3 as HCO3	0	61.0	0.0	0.0
CO3 as CO3	0	30.0	0.0	0.0
CO3 as CaCO3	0	50.0	0.0	0.0
			136.9	100.0

QAL-2
3/7/2006
GROUNG WATER QUALITY
TRI-LINEAR DIAGRAM

ION	mg/l	Factor	meq/l	%
Sodium	838	23.0	36.4	42.9
Magnesium	334	12.2	27.4	32.3
Potasium	9.2	39.1	0.2	0.3
Calcium	418	20.1	20.8	24.5
			84.8	100.0
Chloride	196	35.5	5.5	5.7
Sulfate (SO4)	4050	48.0	84.4	87.4
HCO3 as CaCO3	334	50.0	6.7	6.9
HCO3 as HCO3	0	61.0	0.0	0.0
CO3 as CO3	0	30.0	0.0	0.0
CO3 as CaCO3	0	50.0	0.0	0.0
			96.6	100.0

QAL-3
3/7/2006
GROUNG WATER QUALITY
TRI-LINEAR DIAGRAM

ION	mg/l	Factor	meq/l	%
Sodium	1530	23.0	66.5	56.8
Magnesium	375	12.2	30.7	26.2
Potasium	25.6	39.1	0.7	0.6
Calcium	388	20.1	19.3	16.5
			117.2	100.0
Chloride	306	35.5	8.6	5.5
Sulfate (SO4)	6800	48.0	141.7	89.9
HCO3 as CaCO3	368	50.0	7.4	4.7
HCO3 as HCO3	0	61.0	0.0	0.0
CO3 as CO3	0	30.0	0.0	0.0
CO3 as CaCO3	0	50.0	0.0	0.0
			157.6	100.0

Qnt

3/13/2006

GROUNG WATER QUALITY

TRI-LINEAR DIAGRAM

ION	mg/l	Factor	meq/l	%
Sodium	2400	23.0	104.3	90.6
Magnesium	90.5	12.2	7.4	6.4
Potasium	2.2	39.1	0.1	0.0
Calcium	68.4	20.1	3.4	3.0
			115.2	100.0
Chloride	1320	35.5	37.2	24.5
Sulfate (SO4)	4800	48.0	100.0	66.0
HCO3 as CaCO3	720	50.0	14.4	9.5
HCO3 as HCO3	0	61.0	0.0	0.0
CO3 as CO3	0	30.0	0.0	0.0
CO3 as CaCO3	0	50.0	0.0	0.0
			151.6	100.0

S-4
11/16/2005
GROUNG WATER QUALITY
TRI-LINEAR DIAGRAM

ION	mg/l	Factor	meq/l	%
Sodium	6420	23.0	279.1	85.7
Magnesium	360	12.2	29.5	9.1
Potasium	10.2	39.1	0.3	0.1
Calcium	339	20.1	16.9	5.2
			325.8	100.0
Chloride	3190	35.5	89.9	26.9
Sulfate (SO4)	10900	48.0	227.1	67.9
HCO3 as CaCO3	785	50.0	15.7	4.7
HCO3 as HCO3	0	61.0	0.0	0.0
CO3 as CO3	0	30.0	0.0	0.0
CO3 as CaCO3	80	50.0	1.6	0.5
			334.2	100.0

S-5
2/14/2006
GROUNG WATER QUALITY
TRI-LINEAR DIAGRAM

ION	mg/l	Factor	meq/l	%
Sodium	1990	23.0	86.5	70.1
Magnesium	275	12.2	22.5	18.3
Potasium	4.3	39.1	0.1	0.1
Calcium	288	20.1	14.3	11.6
			123.5	100.0
Chloride	650	35.5	18.3	13.3
Sulfate (SO4)	5200	48.0	108.3	78.5
HCO3 as CaCO3	550	50.0	11.0	8.0
HCO3 as HCO3	0	61.0	0.0	0.0
CO3 as CO3	0	30.0	0.0	0.0
CO3 as CaCO3	20	50.0	0.4	0.3
			138.0	100.0

KPC
3/8/2006
GROUNG WATER QUALITY
TRI-LINEAR DIAGRAM

ION	mg/l	Factor	meq/l	%
Sodium	1390	23.0	60.4	94.4
Magnesium	20.6	12.2	1.7	2.6
Potasium	8	39.1	0.2	0.3
Calcium	34.1	20.1	1.7	2.6
			64.0	100.0
Chloride	352	35.5	9.9	11.8
Sulfate (SO4)	1640	48.0	34.2	40.7
HCO3 as CaCO3	1990	50.0	39.8	47.4
HCO3 as HCO3	0	61.0	0.0	0.0
CO3 as CO3	0	30.0	0.0	0.0
CO3 as CaCO3	0	50.0	0.0	0.0
			83.9	100.0